Commentary

RESEARCH IN TECHNICAL COLLEGES IN THE PROVINCES

IT IS sad to find people in high places in the fields of education and industry who believe that technical colleges are second rate establishments and that research workers in them must also be inferior because the brightest brains, they think, seek employment in the universities where prestige is unquestioned. These men, and there are many of them, see no difference in function between university and technical institute and they look on the latter as a cheap imitation of the former and as a refuge for the failures, both staff and students, who have not gained admission to university as lecturers or undergraduates. For those who hold this uncomplimentary and unenlightened view a visit to some of the provincial technical colleges would be a voyage of discovery.

The three leading Colleges of Advanced Technology which should be seen in this connection are Bradford, Birmingham and Salford. The Bradford college, as one would expect from its location, is very much concerned with research in textiles, particularly in wool and in man-made fibres. It has other research pursuits also. Bradford has a full time teaching staff of a hundred and twenty-six, of whom eighty-two are engaged in research as well as in teaching. It has twelve industry sponsored research staff and nineteen other research fellows, assistants and scholars provided by the Institute of Technology. In the space of a few years Bradford's research work has grown enormously.

The Royal Technical College, Salford, has an impressive research programme in hand this season. Sixteen projects relate to building and civil engineering, the department of chemistry and applied chemistry lists twenty-four, electrical engineering ten, mathematics five, the department of mechanical engineering nine, and the department of pure and applied physics eight. It is realized that the level and quality of research cannot be measured in terms of the number of projects, but the long list of Salford's research activities is a measure at least of this college's vitality. Salford, like Bradford, is keen to further its industrial contacts and some of its projects point to close links with industry. The much neglected machine tool industry, to quote just one case, is receiving attention from Salford's Royal Technical College. It is such projects that the Department of Scientific and Industrial Research is interested in and may be prepared to finance.

The Birmingham college's research is vast and varied. This college of technology is the proud possessor of an industrial research fellowship donated by the Wilmot Breedon concern. It is valued at £1000 a year, is normally held for two years, and is awarded by a committee made up of representatives of the college and firm. The first award was made in 1958 when the company was so impressed by the high standard of the applicants all of whom were graduates and had either industrial or research experience, that two fellowships instead of one were offered. The terms of the scheme were designed to bring factory and college together and a Wilmot Breedon fellow may undertake his research in either place. The enterprise chosen for research must come within the main activities of the company —electronics, hydraulics, metallurgy, metal finishing, metal formation, electro-chemistry or mechanisms —and candidates are advised to visit Wilmot Breedon's works and laboratories to see what is being done there and to discuss with company executives their ideas on suitable projects.

The Birmingham college has in the region of twenty research assistants and many of its staff undertake research work. Projects are under way in chemistry, electrical engineering, mechanical engineering, metallurgy, physics, pharmacy and biology, and in the department of industrial administration. The college has been helped with its work by industry as a visit to its mechanical engineering department will demonstrate, for housed there are gifts of equipment which bear the names of the motor vehicle manufacturers making and donating them.

A near neighbour of the Birmingham C.A.T. is the Lanchester college of technology at Coventry. This college has not yet been formally opened and until later this year it will go on being accommodated in the building of the Coventry technical college. When the new building is ready, the senior work from the Coventry college will be transferred to it and the signs are that Lanchester, though not designated a C.A.T., will soon show its strength as a major technological institute. Already it has earned a research tradition for itself; research is being carried out in the departments of chemistry, metallurgy, textiles and electrical engineering.

In 1945 the college's chemistry department embarked on an important research project in

conjunction with Birmingham university. Analytical chemistry was its main theme, and the activities of the college in this joint endeavour resulted in the publication of a set of qualitative analysis tables which are much used in schools and colleges in the Midlands. In 1959 a review of the G.C.E. advanced level practical examinations in chemistry showed that pupils from schools using these tables reached a standard higher than average. The chemistry department receives regular requests from local industry to undertake consultancy work, invitations which show that its research activities and results are greatly respected. This department has been given a contract by the Atomic Energy Research Establishment at Harwell, and its work has broadened out in other directions also. Research in textiles, again indicative of the college link with local industry includes investigations into the creasing properties of fabrics. Another activity that the college is engaged on with Birmingham university is in the field of nuclear energy where research is in progress relating to the characteristics of particle tracts.

What the Lanchester college has done in this way has been done under difficulties of accommodation. The new building which has been designed with advanced teaching and research in mind will make other projects possible and it seems likely that the Lanchester college will be greatly helped by the progressive members of local industry with whom it has long enjoyed a close and lively working partnership.

The Hatfield college in Hertfordshire is very keen on research and is encouraged to develop it by an understanding county authority. Three years ago the governing body of the college set up from its members a research sub-committee to study the whole question of research and to draw up a college plan to deal with it, and they appointed to it two university professors, a university research director and one education officer. Applications from staff wishing to undertake research go via their heads of departments to the research committee for consideration. Approval of a project means that the member of staff concerned may embark on it for a trial period of twelve months and if his progress is satisfactory the research committee will recommend a reduction of his teaching load by three hours a week. Ten staff at present have this concession and other staff have been appointed to fill the gap of the lost hours. Progress reports together with an estimate of equipment and materials required must be submitted annually so that the committee may determine whether or not this particular research will continue to enjoy their patronage.

Research at Hatfield is being undertaken in the departments of science, of commerce, social and professional studies, electrical engineering, aeronautical and mechanical design, and mechanical and production engineering. It is interesting to note that the research committee has been examining the D.S.I.R. awards schemes and the best ways of utilizing them. Hatfield is one of the newer colleges and is well able to undertake research. Its science wing is particularly well equipped with first class research laboratories.

An unusual research feature is to be found at the Wolverhampton and Staffordshire College of Technology. Although the college does research in its own right and has an establishment of six research fellows reading for higher degrees, it has housed in its building a small research group from the British Coal Utilisation Research Association. Some of this college's research projects are in the fields of fuels, pneumoconiosis, tool wear, boiler wear, and radio-chemistry.

The biggest drawback to research in technical colleges is time. The teaching load is often between fifteen and twenty hours a week, which may include evening work, and perhaps half a day may be spent on research. It is a ludicrous situation. How much research can be done on that weekly basis, and how much energy and enthusiasm will be available for it after a heavy teaching programme? It is evident from this survey, short as it is, that not enough research in these colleges is being backed by industry or being done jointly with it, and one of the reasons why this is so is that technical college staff do not have time to go out and about to see industry's wheels turning. It is possible for the Readers to make contacts but they are few in number and they are only to be found in the C.A.T.s. For all teaching staff in departments giving service to industry, whether engineering in its many divisions or in industrial management and the human sciences, industrial visits should be classed as part of their normal working programme.

And just as some staff in colleges in the London area regretted the prestige given to research so do some staff in colleges in the provinces feel the same kind of disquiet. Prestige is measured by some in terms of the size of research awards and the sufferers from this kind of competition find the whole subject of research so tiresome that they are determined to keep clear of it at any cost.

BREWING

W. P. K. FINDLAY

The Brewing Industry Research Foundation, Redhill

Production of beer from barley and hops involves four main steps: (*1*) malting of barley; (*2*) extraction of wort from malt; (*3*) boiling of wort with hops, and (*4*) fermentation with yeast of sterile hopped wort. In the past these processes have been carried out batchwise in large vessels. Recent developments at the Brewing Industry Research Foundation in Nutfield and elsewhere suggest that the continuously operated processes involving an increased degree of instrumentation will enable much higher rates of production to be obtained from vessels of any given size than is now possible in conventional plant. This is the first article of a series on *Biochemical Engineering*.

TRADITIONAL methods of malting and brewing do not require any elaborate or complicated plant. As the industry has become centralized into larger units through the amalgamation of breweries, so has there been a tendency for larger vessels to be built, but for the most part they are still of essentially the same design and function.

The production of beer from the raw materials, *i.e.* barley and hops, involves four main steps: firstly the conversion of the barley grain into malt by germinating it under controlled conditions, secondly the infusion or mashing of the ground malt with warm water to produce sweet wort, thirdly the boiling of the sweet wort with hops to give a sterile hopped wort and finally the fermentation of this wort by yeast to yield beer with an alcohol content usually of 4–8 per cent but occasionally rather higher, depending on the original gravity of the wort used. Today relatively little high gravity strong ale is drunk and the public taste seems to be tending towards lighter, sweeter and less bitter beers.

Malting

Much barley is still malted by spreading it out on a floor to germinate after a preliminary steeping in tanks full of water. While on the floor it may be turned by hand shovelling or by mechanical means. In the compartment or box system the germinating grain is processed in an open rectangular structure with a perforated metal floor, where the grain is mixed by screw-type turning machines that slowly travel the length of the compartment. In most of the modern installations the steeped barley is poured into large drums which may contain over one hundred quarters of barley (a quarter of barley equals 448 lbs). The drums are rotated slowly, being turned once or twice an hour. Humidified air is pumped continuously through the drums to remove the carbon dioxide given off by the germinating grain. The temperature of the air is controlled by the temperature of the water used in the air-conditioning plant.

When germination has proceeded for long enough for the whole of the endosperm to have become 'modified' and softened, which under the conditions employed in Great Britain usually takes seven or eight days, the green malt is then dried in a kiln which consists of a large room with a perforated floor, through which rise the hot gases from a furnace, which burns either solid or liquid fuel.

In order to ensure that the arsenic content of the final beer does not exceed the statutory limit of 0·2 parts per million, it is important that the arsenic content of anthracite fuel used in maltings should be low. Standard methods for determining the arsenic content of anthracite have been agreed and an upper limit in the fuel for this element has been proposed. The malt is turned mechanically while it remains for three or four days on the floor of the kiln, so as to ensure that it is dried uniformly. The finishing temperature may be about 170–180°F which ensures the development of the malty flavour and a final moisture content of 4·0 per cent or less. The temperatures used during curing and drying affect the colour and flavour of the malt and for special purposes the final temperature may be considerably higher.

During its conversion into malt, barley suffers a loss of about 9·0 per cent of its dry weight, due in part to its respiration and in part to the production of rootlets which are removed before the malt is used for brewing. Certain modifications of the malting procedure have recently been suggested as a result of work at the Brewing Industry Research Foundation by which this malting loss may be reduced to 4–5 per cent. These involve re-steeping the barley for about twenty-four hours after it has been allowed to germinate for three days, by which means the young rootlets are killed off and their substance largely reabsorbed. While this re-steeping procedure may not be readily applicable to floor maltings, it should not be difficult to modify a drum malting plant, so as to permit re-steeping of the grain while still in the drums. Dried malt can be stored for a considerable time before it is used and is usually shipped in airtight drums to prevent its re-absorbing moisture.

Mashing

The first stage of brewing beer is to extract from the malted barley the sugars, dextrins and other substances made soluble by the enzymes formed by the embryo during germination of the grain and during the subsequent stage. This process which is known as mashing, is generally carried out in a large round vessel—the mash tun—into which the malt mixed with water at a temperature usually at 140–150° F is poured in the form of a thin 'porridge'. The so-called 'goods' are then allowed to stand for one and a half hours, during which time the starch is almost entirely converted into sugars, mainly maltose and some break-down of proteins occurs. In English breweries the solution of sugars known as sweet worts are drawn off directly from the mash tun which is provided with a slotted base plate, but in continental lager breweries the whole of the mash is pumped forward into a Lauter tub or straining tank. The operations of filling and emptying a mash tun take a considerable time for in many breweries the spent grains are still shovelled out by hand and efforts have been made to design plant that would operate continuously and yield wort of constant composition. One such device recently developed at B.I.R.F. takes the form of a rotary mash tun in which the mash is filled in succession into a number of sections formed by the provision of radial vanes which are slowly rotated so that the whole body of mash is moved round over a stationary base plate. The first half of the plate is solid, the latter half is slotted so that the sweet wort can filter through the bed in the normal way. There are arrangements for automatic sparging of the grains and for counter-current recirculation of the last runnings (the weakest worts), so as to achieve worts of higher gravity when required. Using this plant it has been found possible to produce wort of normal composition continuously; this can be fermented to give beer indistinguishable from that made from wort produced in a conventional mash tun. By continuous operation it is possible to produce a surprisingly large volume of wort from a small vessel; for instance a mash tun only 18 in. in diameter can produce between eighty and a hundred barrels per week (a barrel equals 36 gallons or 1·64 hectolitres). Pilot plant for continuous mashing using a rotary table filter of this kind is now being developed by plant manufacturers in cooperation with various large breweries.

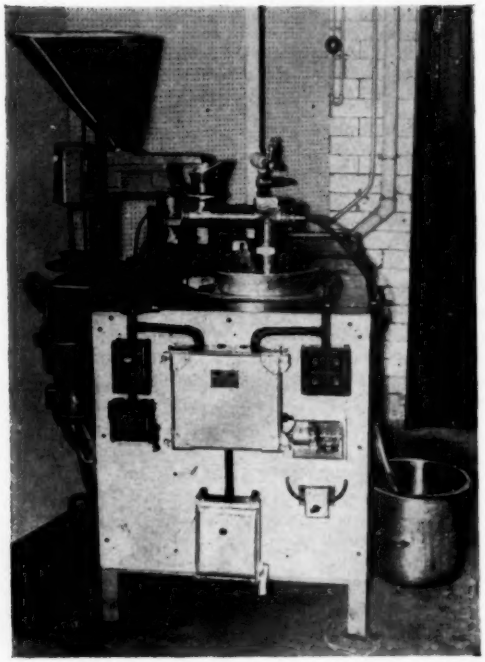


Figure 1. General view of experimental rotary mash tun for continuous production of wort. (Courtesy B.I.R.F.)

Wort Boiling and Hop Extraction

The wort that comes from the mash tun must be boiled in order to sterilize it and to inactivate the enzymes derived from the malt. During the process much of the protein is coagulated and precipitated as the so-called 'hot-break'. The hops may all be added at the beginning of the boiling, which normally takes one and a half hours, or a proportion of them may be added towards the end so that more of their aroma is retained. Hop rates vary according to the type of beer being brewed but in this country 1 lb of hops per barrel is about the average. As a considerable loss of the valuable bittering substances in the hop occurs during boiling when a proportion is lost on the 'break' there is room for much improvement in the efficiency of this process.

An ingenious arrangement for continuous boiling and hop extraction has recently been developed at Brewing Industry Research Foundation. In this apparatus the boiling wort is percolated a number of times over a slowly moving stainless steel belt carrying a thin bed of hops. Preliminary results

suggest that considerably improved utilization of the hops will be achieved in this way.

Even more effective utilization of the bittering principles in the hop would be achieved if they could be extracted from the hops and added continuously either to the already boiled wort or to the fermented beer in the correct proportions by a metering pump, but methods for preparing hop extracts of adequate quality for this particular purpose have still to be devised. There is no doubt that when continuous brewing becomes a common commercial practice in this country, interest in the use of previously prepared hop extracts will develop.

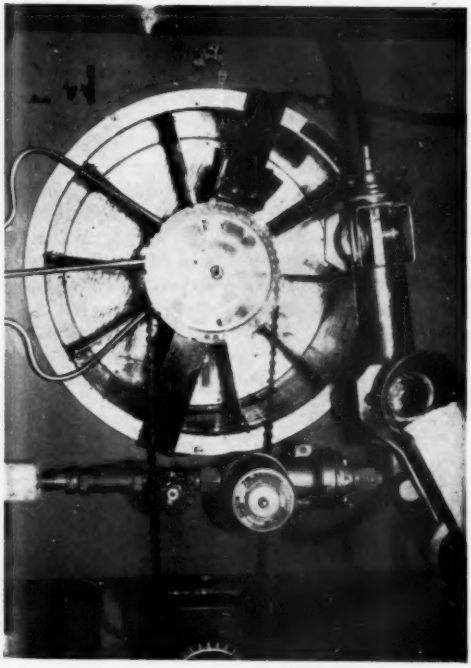


Figure 2. Plan view of rotary mash tun showing the radial vanes that move the mash over the base plate. (Courtesy B.I.R.F.)

Fermentation

After cooling, which is today usually effected in paraflow coolers the sterile hopped wort passes to the fermenting vessel where the yeast is added by 'pitching' in approximately one pound of thick liquid yeast for each barrel of wort.

In this country open fermenting vessels are generally employed. To anyone accustomed to the pure culture of micro-organisms required for the production of antibiotics, the methods of the brewer might at first seem crude in the extreme. If however the vessels have been properly cleaned and the buildings are generally kept in a clean hygienic condition little trouble with contamination is normally experienced. The reasons for this are firstly that the hop resins are appreciably toxic to many micro-organisms, and secondly the 'inoculum potential' of yeast is very high so that the growth of the yeast soon swamps that of any contaminating micro-organisms, and with rising acidity the medium soon becomes unsuitable for coliforms and many other bacteria.

It is of course highly important that the pitching yeast itself which is used to start the fermentation should be freed from potentially troublesome contaminants. The so-called top fermenting yeast used by brewers for the production of ales are all varieties of *Saccharomyces cerevisiae* while those used for brewing lager beers are classified as strains of the closely related species *S. carlsbergensis*, and are commonly called bottom fermenting yeasts. Few breweries in the United Kingdom employ pure culture techniques for propagating their yeast and most of the yeast used consists of a mixture of strains which differ in their flocculation characteristics. Brewers yeast usually contains a small proportion of living bacteria which from the standpoint of human health are completely harmless. The commonest of these is *Flavobacterium proteus*, an organism that appears to interfere but little with the normal course of fermentation.

Open fermenting vessels which nowadays may be of very large size were traditionally made of timber staves for which New Zealand Kauri pine was the favoured species, but this has long been unobtainable. Douglas fir is probably the most suitable timber now available for constructing vats. It is difficult to keep the interior surface of the wooden vessels clean and free from infection especially after they have become softened by continuous use and various lining materials have therefore been used. Many brewers have lined their old wooden vessels with thin copper or stainless steel or even as a temporary measure, with a thick polythene film. Slate provides an impervious and durable surface which can easily be cleaned and slate-lined vessels over one hundred and fifty years old are still in use in at least one large brewery in London. In the north of England, square or rectangular vessels lined with slabs of slate were used in the Yorkshire 'Stone Squares'. Glass-lined tanks have also been

used but are rather liable to be damaged during cleaning operations. There are also thermoplastic proprietary materials which can be applied to concrete and which give a jointless marblelike finish to concrete, which is easy to clean. These are said to last extremely well.

Most breweries today are using stainless steel for any new vessels that are being erected to replace out of date and worn out plant and where new breweries are being erected overseas, as for example in the Caribbean area, most of the plant is constructed in stainless steel. Some of the most recently erected stainless steel fermenting vessels are of very large size, up to 300,000 gallons capacity.

A number of aluminium vessels have been erected but this surface is rather liable to be damaged during cleaning operations and any saving in cost *vis-à-vis* stainless steel, which has so many advantages, is probably in the long run illusory.

Continuous Fermentation

The production of beer by continuous fermentation in closed vessels into which sterile wort is pumped continuously and from which finished beer pours continuously has been shown to be perfectly feasible and is already operated on a commercial scale in New Zealand. The system offers many advantages over the traditional batch methods among which the following are the most outstanding. A much larger volume of beer can be produced per day from plant of any given size because: (*a*) no time is wasted in filling, emptying and cleaning the vessels between each brew; (*b*) fermentation is always proceeding at its maximum rate, as the yeast is at all times growing actively in the log phase and is kept in contact with the nutrient wort by continuous stirring; and (*c*) fermentation can be carried out at temperatures considerably above those normally employed in brewing since no autolysis of yeast occurs and acceptable beers have, under laboratory conditions, been brewed at temperatures as high as 85°F. In a fully continuous brewery the demands for steam would be more constant, high peak loads could be avoided and a smaller steam raising plant would be necessary than is required for batch working.

The system also provides scope for instrumentation with built-in control mechanisms which would be capable of adjusting the flow rates to ensure uniform gravity in the outflowing beer.

On a laboratory scale in the Brewing Industry Research Foundation it has been found possible to brew beers of varying type and character in a continuous apparatus and the system should in no way restrict the brewer in his choice of brewing materials or yeast. During the past year the development of the process has been carried a stage further at the Foundation; pilot plant capable of producing five to eight barrels of beer per week has been erected in which, starting from commercial samples of wort, beer has been brewed which was considered to be indistinguishable from beer produced from the same wort by a batch fermentation in the brewery. In this plant there are two closed fermenting vessels, each of thirty gallon capacity which can be used independently or in series when it is desired to effect the fermentation in two stages and there are arrangements for stirring the contents at any desired speed. In general a single-vessel system operates quite satisfactorily but certain strains of yeasts that are sensitive to high concentrations of ethanol may operate more efficiently in a two-vessel system in which the first part of the fermentation can proceed rapidly in a low concentration of ethanol.

Fully attenuated beer overflows from the fermenters into a chilled yeast separator in which most of the suspended yeast flocculates so that the finished beer is sufficiently free of yeast to be cleared by 'fining' with a solution of isinglass or by centrifugation. A device for the continuous introduction of an appropriate quantity of finings to the beer leaving the yeast separator has been designed, so that the beer could be then passed either into conditioning vessels or directly into casks.

Conditioning

After the main fermentation has been completed the beer is drawn off into large conditioning vessels or casks in a cold room where it may remain for a period varying from a few days up to several weeks. A little sugar may be added as a priming in order to stimulate some secondary fermentation and a small amount of dry hops, say 1 or 2 oz to the barrel, may also be added to increase the hop aroma of the beer.

Draught beer in this country is usually clarified by the addition of isinglass finings which react with and precipitate any yeast still in suspension.

Beer for bottling is filtered through sheet or Bowser type filters. Commonly a rough filtration is followed by a final polishing filtration to ensure the brilliancy demanded today in bottled beer.

When brewing a beer of lager type the usual practice on the continent is to store the beer in the cold for periods of up to twelve to sixteen weeks after the main fermentation has been completed. While some improvement in flavour may result from this prolonged cold storage, its main purpose seems to be to bring about the precipitation of the tannin–protein complexes which would otherwise

cause the lager to become hazy when chilled before drinking. Prolonged cold storage not only involves the tying up of much capital in the form of duty paid beer and extensive cold storage tanks and plant but also considerable running costs for the refrigeration of the cold stores. All types of beer become hazy and therefore unsaleable after prolonged storage. Sometimes this may be due to the growth in the beer of wild yeasts or bacteria but with present methods of brewing the haze is generally of a non-biological nature and the haze-forming materials are certain protein fractions which combine with tannins derived from the hops and the husks of the malt. Proteolytic enzymes prepared from papain are sometimes added to the finished beer in an attempt to remove the protein fractions involved in haze formation. Analysis of this haze has revealed that the particular tannins mostly concerned are the anthocyanogens which, on treatment with acid, yield the flower pigments cyanidin and delphinidin. A means for removing selectively these particular compounds by absorbing them on *Nylon 66* powder has recently been developed at the Foundation. To achieve a doubling of the useful shelf-life of bottled beer it is necessary to remove only about 30 per cent of the anthocyanogens and this can conveniently be done by passing the beer through a short column of loosely packed nylon powder, which can readily be regenerated and re-used after treatment with dilute alkali. The most convenient means for utilizing the material to advantage on a commercial scale are being studied in several breweries and perhaps suitable filters incorporating nylon powder will prove to be the best arrangement for general purposes.

Bottling

The proportion of beer sold in bottles and cans has increased greatly during this last few years and considerable improvements in the arrangements for bottling and pasteurizing the product have been introduced into some of the larger breweries where extremely high rates of working can be achieved with some of the new automatic filling machines. Machinery for effectively washing similar numbers of bottles is also available. A recent development on the Continent has been the introduction of hot bottling, but so far this does not appear to have been adopted in this country. In this process the beer after the normal period of cold storage is placed under a pressure of about eight atmospheres and its temperature is then raised to 62°C in a plate heat-exchanger. The pre-heated bottles, which must be specially cleaned to free them from all solid particles, are filled by running the beer which contains about 2·5 volumes of CO_2 smoothly down the sides of the bottle against a suitable counter pressure of air. The main advantages derived from the system are that it obviates the need for a pasteurizer and reduces the amount of air in the head-space in the bottles, thus increasing the stability of the beer, but it is admitted that bottle breakage may be somewhat higher than normal.

The presence of any large amount of air in the head-space of the bottle tends to accelerate the formation of haze and also increases the risk of off-flavours being formed during pasteurization. It is therefore highly desirable that the volume of air in a bottle should be kept to a minimum and this can best be achieved by causing the beer to foam sufficiently to drive most of the air out of the bottle before the crown cork is fixed on. In some breweries this foaming or ' fobbing ' as it is called is induced in a controlled manner by an ultrasonic vibrator but usually it is brought about by causing each of the filled bottles to be tapped mechanically at an appropriate point. If the amount of air in the head-space is not too great the addition of a small amount of ascorbic acid to the beer will reduce the risk of oxidation.

Pasteurization is generally carried out by exposing the bottles to a temperature of 135°F for twenty minutes for heating up to this temperature and twenty minutes for subsequent cooling.

Conclusion

Up to the present, the plant and vessels used in brewing have been largely traditional in their shape and methods of operation, and modernization has mostly involved an increase in the size of the vessels and changes in the materials of which they are constructed. Mechanization and automation have been introduced mainly at the packaging end, where the speed and effectiveness of bottling machinery have been greatly improved. An appreciable and increasing proportion of beer, particularly of the lager type that requires chilling before use, is now being supplied in cans.

Radical changes in brewing methods involving the production and fermentation of wort by continuous methods are foreseen and in all probability will soon be adopted, together with an increasing degree of instrumentation and automatic control of quality.

VERTICAL TAKE-OFF—A SURVEY

D. KEITH-LUCAS

Short Brothers and Harland Ltd, Belfast

A survey is made of vertical take-off aircraft of all sorts from the balloon to the interplanetary rocket. The various aircraft are classified according to their lifting systems and an attempt is made to indicate their suitability to different operational rôles. It appears that cruising speed is the most important factor in determining the efflux velocity and hence the type of lifting system.

LEONARDO DA VINCI is generally credited with the invention of the helicopter yet it took another four hundred years before anyone made it work. The delay was due, almost entirely, to the need to develop two things—a light enough engine and a satisfactory means of controlling the aircraft in the air.

These two problems also dogged the development of fixed wing aircraft and it was by making advances in these fields that the Wright brothers made their greatest contribution. Wilbur Wright is reported to have said ' A barn door can be made to rise in the air if inclined at an angle and with sufficient power behind it. But that is not flying. The problem is to keep it in the air and that involves means of control and balance.'

For conventional aircraft today we have sufficient power and we also have the means of control and balance, but for a vertical take-off aircraft we need still more power or, at least, more thrust and the well-tried means of control and balance are no longer applicable. The problems of vertical take-off and landing are, indeed, the same old problems but intensified.

It is to solve these problems that a breed of strange new aircraft has appeared throughout the world—Flying Bedsteads, Tail Sitters, Flat Risers, Fan Lift Vehicles, Tilt Wing aircraft, aircraft with Deflected Slipstream or Deflected Jets, Convertiplanes and many other strange contraptions which seem to have little in common but the apparent ability to lift themselves by their own bootlaces. They are the research aircraft which are being used to tackle the problems at life size and here and there about the world is an even greater multiplicity of drawings, calculations and models—some of them even more peculiar—which tackle the problems in miniature.

It was another of Wilbur Wright's famous sayings that ' If you are looking for perfect safety you will do well to sit on a fence and watch the birds; but if you really wish to learn, you must mount a machine and become acquainted with its tricks by actual trial.' That is what is being done and what has caused this profusion of strange machines.

Aeronautics needs a Linnaeus to define and classify the different species. Without him the words ' vertical take-off and landing ' or ' V.T.O.L.' are being used to describe a series of totally different aircraft ranging from the balloon to the interplanetary rocket. This is confusing. Let us, then, use ' V.T.O.L.' and ' S.T.O.L.' to describe only the manner in which the aircraft is operated.

The zoologist recognizes that similarity of appearance, behaviour or habitat is an insufficient clue to membership of the same family. One must look more closely and find correspondence between the actual organs of the body. Thus a genus is defined as ' a group of species possessing certain structural characteristics in common by which they are distinguished '. The zoologist also looks for evidence of derivation or evolution from a common origin.

Perhaps we should follow something of the same reasoning in classifying aircraft. We can distinguish first the ' powered lift ' from the ' lighter-than-air ' or ' buoyancy lift ' aircraft.

It is unnecessary to give much attention to the lighter-than-air craft as they are now outmoded but it is well to remember that the airship was the first V.T.O.L. airliner by a very long way. The balloon is the invertebrate of the aeronautical world and, as in the animal kingdom, has not developed to anything like the same extent as the vertebrates.

Powered lift aircraft are those that derive their lift either directly or indirectly from the power of an engine. With present day engines this means that the lift is generated by the chemical energy contained in the fuel. Perhaps in future it will be generated by nuclear energy but it will still come ultimately from the fuel.

We can distinguish between those powered lift aircraft which employ ' direct lift ' and those that employ ' indirect lift '.

Indirect Lift

Indirect lift implies that the engine thrust is not used to lift the aircraft directly but to induce a pressure distribution on the structure of the aeroplane in such a way as to provide lift. The commonest example is the conventional, fixed wing aircraft in which the engine thrust is used to propel the aircraft through the air and it is the air flow over the wing which creates the pressure distribution and hence the lift. Such aircraft can achieve short take-off by having large wing area or high lift flaps. The *Prestwick Pioneer* is an example. So also is the *Breguet 941* which uses propeller slipstream over the whole wing span to enhance the wing lift. It is capable of very short take-off and landing but the *Ryan Vertiplane* and *Fairchild VZ-5FA* go a stage further and actually achieve vertical take-off and landing by the same means. These are usually known as ' deflected slipstream ' aircraft (*Figure 1*).

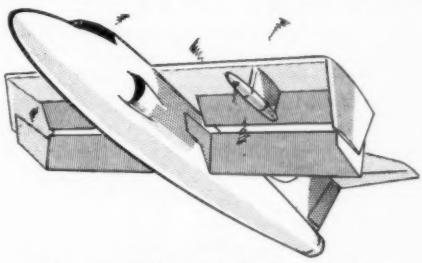


Figure 1. Deflected slipstream aircraft

An alternative approach is to use the engine power to blow air at high velocity over the flaps. This increases the lift by ' super-circulation ' as opposed to, say, the Breguet 941 which increases the lift by ' super-velocity '. Taken to the limit, the blown flap leads to the jet flap which is simply a curtain of air issuing downwards from the trailing edge. The capabilities and limitations of the jet flap have not yet been explored in actual flight. Wind tunnel tests have shown that if the efflux gases of a jet engine are used in this way, the resultant increase in lift, even at very low forward speeds, is several times the thrust of the engine. The idea is therefore attractive but unfortunately the gain is much less on wings of low aspect ratio, as used for high speed flight, than on wings of high aspect ratio which are suitable only for low speed flight.

A totally different type of indirect lift is the ' ground cushion '. In this type the presence of the ground is used to create a pressure on the underside of the vehicle. For this purpose the vehicle has some sort of lifting pad or plenum chamber fed with compressed air underneath. An example is the *Saunders-Roe Hovercraft*. It is debatable whether such craft are really aircraft or surface vehicles as they are not able to rise out of the ground cushion. They have the advantage over wheeled vehicles that they can traverse rough ground, marshland or water and the principle is likely to find application as assault craft, for ferry work especially over estuaries and, possibly, cross channel also although the craft will need to be very large if they are to clear high waves.

One can argue that these craft are not V.T.O.L. insofar as they never really take-off, but there is the intriguing possibility that the principle might be applied to replace the normal undercarriage. This would achieve one of the objects of V.T.O.L., namely to dispense with concrete runways. A clear run would still be needed but the ground loading could be made so light that concrete would be unnecessary.

In looking for a name for these craft one is tempted to look to the zoological analogy and call them ' gastropods '—animals which crawl upon their bellies.

If the requirement is genuinely for V.T.O.L., that is to say for no run at all, we will usually have to look to direct lift. The dividing line between direct and indirect lift is not always clear. A helicopter rotor can be regarded as a means of turning power into thrust (*i.e.*, as a special case of a propeller). Seen in this light the helicopter engine is providing direct lift. Alternatively, the rotor can be regarded as a rotating wing which derives its lift from the speed with which it passes through the air. In this light it is indirect lift.

The view taken in this article is that it is more logical to regard the rotor as part of the thrust-producing mechanism than to regard it as part of the structure of the aircraft. The helicopter has therefore been classified as a direct lift aircraft.

By the same argument the deflected slipstream aircraft are included under indirect lift, the view being taken in their case that the wing is part of the aircraft structure and not part of the thrust-producing mechanism.

Direct Lift

Direct lift aircraft can be divided conveniently into five classes according to the means employed for generating the lift. They are rotorcraft, propeller lift, fan lift, jet lift and rocket lift.

Table 1

	Disc loading lb/ft²	*Efflux velocity* ft/sec	*Static thrust per h.p.* lb/h.p.
Helicopter rotor	5	35	15
Propeller	60	150	2·5
Fan	260	500	2·0
Pure jet	2500	2000	0·75
Rocket	7500	6500	0·04

The important difference between these types is the efflux velocity from the lifting system. *Table 1* shows a comparison.

The higher efflux velocities have disadvantages with regard to noise and ground erosion as well as the more fundamental one of engine power required and fuel consumed.

For examples, on the above figures, if we compare two aircraft of the same all-up-weight, one a helicopter and the other having pure jet lift, we find that the jet lift aircraft needs twenty times as much power. Moreover, if the two are powered by gas turbines of equal efficiency it also needs twenty times as much fuel.

The advantage of the high efflux velocities is the small size of the installation and the consequent low drag in forward flight. In practice therefore the high efflux velocities are used for high speed aircraft and the more efficient, low efflux velocities for low speed aircraft.

The high fuel consumption associated with jet lift makes it uneconomical for the aircraft to remain jet-borne for any length of time. Such aircraft must therefore undergo a ' transition ' or ' conversion ' to wing-borne flight for the main part of their journey. In this connection a wing can be regarded as a form of thrust augmentor. For example a wing with a lift–drag ratio of twenty in combination with a jet engine which is used for propulsion, that is to say for overcoming the drag, will give a lift of twenty times the jet thrust. This is the same order of difference as that between the helicopter rotor and the jet engine.

The word ' convertiplane ' has been coined in the United States to describe aircraft which take off and land by direct lift but in cruising flight are supported by indirect lift. So far the word has generally been applied only to helicopters. If in cruising flight only part of the lift is transferred to the wings, they are known as ' compound ' helicopters.

Rotorcraft

The term ' rotorcraft ' is used to denote any aircraft supported by a rotor and includes helicopters, autogyros, compound helicopters, *etc.* These types are also referred to as ' Rotary Wing ' aircraft; a word which was used originally to describe the autogyro and which is best confined to those which, in the event of a power failure, can glide to earth as an autogyro with the rotor turning by autorotation. It would be inappropriate to an aircraft on which the rotor is little larger than a conventional propeller.

The helicopter is still the only operational aircraft capable of V.T.O.L. In its present state of development it is limited to an uneconomically low cruising speed for which reason it is unable to compete on the airlines with fixed wing aircraft. Yet its rotor is the most efficient lifting system for hovering flight which has yet been devised. Consequently it finds its main applications either on short ranges where the low cruising speed is of little account or in specialized rôles where the ability to hover is of more importance than cruising performance. These rôles include submarine detection, air–sea rescue, mountain and flood rescue, aerial crane and so on.

The helicopter is much used in out of the way places where airstrips are not available. Its mechanical complexity and ungainliness are then serious disadvantages.

Efforts are therefore being made to develop fan lift vehicles which are intended to be simpler and more compact and which should therefore be more suitable as ' flying jeeps '.

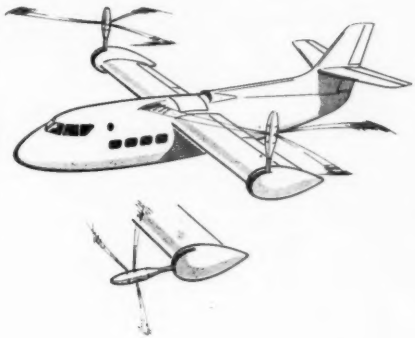
The difficulty arises that making them more compact inevitably means reducing the area of the lifting disc and therefore means an increase in the slipstream or efflux to restore the lift. Reference to *Table 1* shows how great the penalty may be in power and fuel consumption.

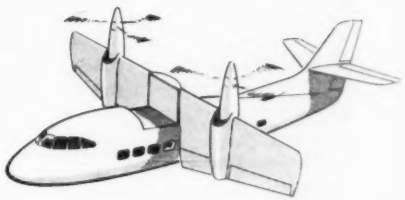
The helicopter is therefore not going to be replaced without a hard struggle and the fan lift aircraft will have to be good if it is going to compete.

There is clearly a need for higher speed aircraft with V.T.O.L. capability. In the civil field they are wanted to operate to inaccessible places where no runways exist, to city centres and, as executive aircraft, to go where the owner wants to go and not only to the nearest airfield. In the military field high performance strike, reconnaissance and fighter aircraft must be made to operate without

runways which are both vulnerable and slow to construct. Military transports and freighters need the same flexibility and independence of operation.

The detail requirements differ according to the rôle. For example the relative importance of speed, economy, noise and ground erosion vary widely but the ultimate object is always the same, to produce a high speed aircraft capable of vertical take-off and landing with the minimum penalty in cost, weight and performance.





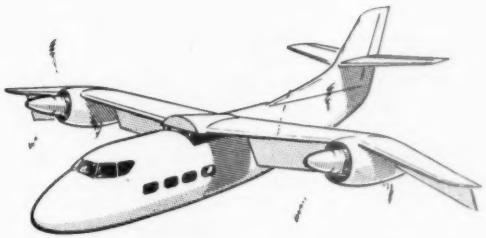


Figure 2. Tilt rotor (above)

Figure 3. Tilt wing (above right)

Figure 4. Tilt wing/deflected slipstream (right)

Two courses of action commend themselves. One is to start with the helicopter and to improve it by circumventing the speed restriction; the other is to start with a high speed aircraft and make it capable of taking off and landing vertically.

Rotorcraft Derivatives

The *Fairey Rotodyne* is a good example of the first approach. It is, in effect, a conventional helicopter for take-off and landing and a propeller driven, fixed wing aircraft for cruising flight. The transition is not, however, complete as the rotor cannot be retracted but serves in autorotation as a supplementary wing. It is therefore a crossbreed between a compound helicopter and a convertiplane.

In America the effort has been directed more towards tilting the rotor through 90° so that in forward flight it acts as a propeller. An example of this is the *Bell XV 3*, in which the propellers or rotors (sometimes referred to in America as 'proprotors') are mounted at the wing tips (*Figure 2*). Other designers have preferred to tilt the whole wing with the engines and propellers; an example is the *Hiller X 18* (*Figure 3*).

Kaman is experimenting with a mixture of wing tilt and slipstream deflection (*Figure 4*). The crossbreed arrangement sounds complicated but in practice it may avoid the difficulties which arise at large angles of wing tilt or large angles of slipstream deflection. In other words, like so many mongrels, it may be better tempered than its pedigree parents!

These American projects are now undergoing flight test but have not yet reached the same stage of development as the Fairey Rotodyne. In any or all of these one can see hopes of development leading to military transport, freighters, short range civil airliners or executive aircraft. On the other hand they are limited to speeds of the order of 300 to 350 m.p.h. on account of compressibility effects which occur on the rotor whether it is used for propulsion or for lift.

For higher speeds we must dispense with the rotor which means either retracting it completely for cruising flight or turning to other forms of lift.

There is undoubtedly a prize awaiting the inventor of a satisfactory rotor retraction scheme. Sikorski

are reputed to be working on a single bladed rotor with the object of making it retractable. The problems are formidable and no practical solution has yet been forthcoming.

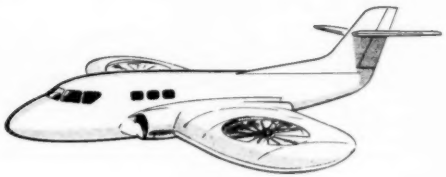


Figure 5. Fan lift.

Fixed Wing Derivatives

For higher speed aircraft we must look to the alternative approach of starting with a high speed aircraft and making it capable of vertical take-off and landing.

Propellers are unsuitable for speeds much above 400 m.p.h. Attention has therefore been turned towards ducted fans as a means both of propulsion and lift.

Doak in the United States have produced an experimental aircraft with ducted fans at the wing tips which can be tilted through 90°. It is a low speed design but the principle is one which could be applied to quite high speeds. Other experimenters have tried to use fans of larger diameter buried in the wing (*Figure 5*). At first sight this arrangement is attractive but it is structurally awkward and there are severe difficulties due to the pitching moment, drag and change of lift during the transition to forward flight. It looks as if the fuselage is a better place to house a fan.

It is worth noting that fans are liable to damage and failure just as are the engines themselves; a multi-engine, multi-fan arrangement is therefore to be preferred to a single-engine or single-fan. Moreover, a fan in each wing is the worst possible arrangement as, if one fan fails, the rolling moment can only be balanced by cutting all power. This is a further argument for putting the lifting system, whether it be fans or jet engines, as near the centre line as possible.

The choice between fans and jets depends largely on the operational rôle. It may be decided by considerations of noise or ground erosion or it may be decided only on which is the lighter. In making the weight comparison we must take account of engine weight, fuel for hovering, effect on the size and structure weight of the aircraft and the effect on drag and hence fuel consumed in cruising.

It appears that at subsonic speeds there is little to choose between a pure jet and a fan augmented jet although further development of fans might give them the advantage. At supersonic speeds, where drag is of first importance, the pure jet looks more promising. Compromises can be made by having more or less fan augmentation and in most cases the choice will have little effect on the layout of the aircraft. We can regard all such engines as jet engines but of varying efflux velocity.

There is one type of fan engine which deserves special attention. It is the type described by S. G. Hooker in his recent James Clayton lecture and is exemplified by the *Bristol Siddeley BE.53*. (*Figure 6*). The novel feature of the engine is that cool air from the fan at the front and the hot air of the jet are not mixed in a common jet pipe but each is channelled through bifurcated jets terminating in nozzles which are controllable in direction. The arrangement is tailor-made for a single engined fighter or fighter bomber—all the thrust being directed upwards for take-off and all forwards for propulsion. It is particularly suited to S.T.O.L. operation as the nozzles can be rotated rearwards for the acceleration along the runway and at take-off speed can be rotated downwards to give the required combination of lift and thrust.

The one serious limitation of this, as of all fan engines, is that it is unsuitable for propulsion at supersonic speeds because the efflux velocity is too low.

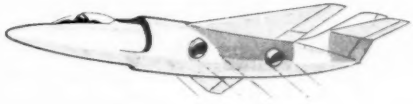


Figure 6. Fan/jet

Jet Lift

There are basically two ways in which jet lift can be provided. One is to deflect the thrust of the propulsive engines; this can be done by deflection of the jet stream or jet pipe or by tilting the complete engine or complete aeroplane through 90°. The other way is to provide separate lifting engines.

The normal design approach would be to decide on the engine thrust required for propulsion and to deflect that thrust vertically. If the resultant lift is inadequate to provide vertical take-off, as would often be the case, the remainder would be made up by separate lifting engines (*Figure 7*). This would

be lighter than increasing the power of the propulsive engines because the lifting engines can be designed for the job. It would also be more economical of fuel in cruising flight because the propulsive engines would not need to be so severely throttled.

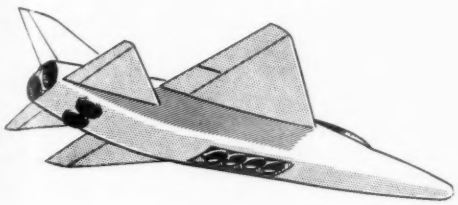


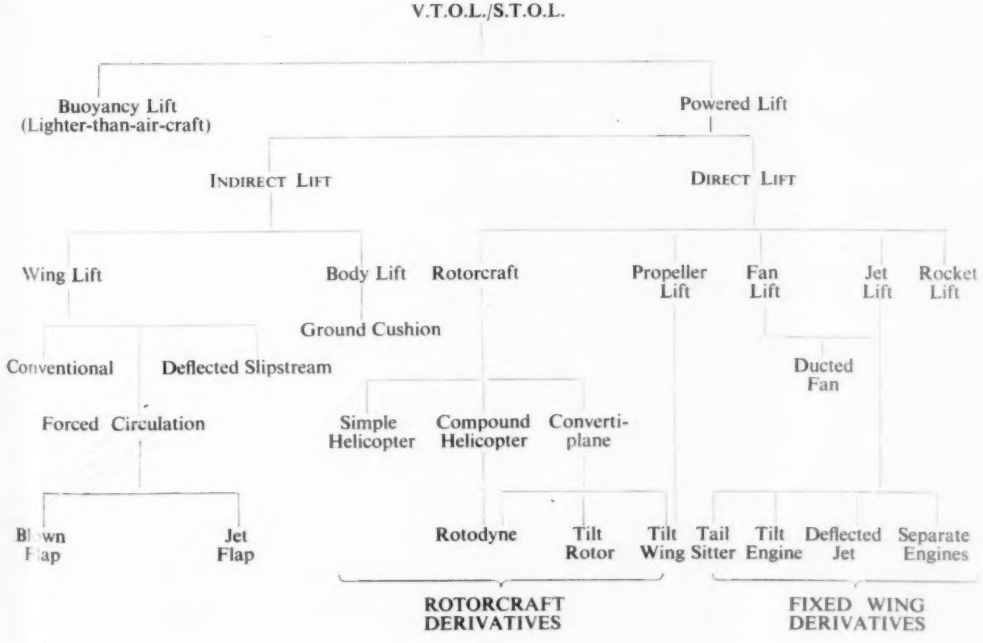
Figure 7. Jet lift

The *Ryan Vertijet* and the *S.N.E.C.M.A. Coleoptere* are examples of 'tail sitters'—jet lift aircraft which stand vertically on their tails at take-off and landing. This method is a straightforward solution to the problem of using propulsive thrust for lift provided that the propulsive thrust is large enough. Moreover, Ryans have shown that the control problems can be overcome successfully and have developed a satisfactory ground rig for raising the aircraft to the vertical attitude, releasing it when the thrust exceeds the weight, catching it again when it comes in to land by engaging a strop with a hook on the aircraft and lowering it once more to the horizontal attitude. The landing or 'hooking on' requires precise flying and the question arises whether it would be operationally feasible.

The 'flat riser' such as the *Bell X 14* and the *Short S.C. 1* has many advantages from the point of view of the pilot and the passengers. It also has the operational advantage that if there is any runway available, the aircraft can use its wings to augment the lift at take-off.

The difference between the American approach and our own is that the Americans have been content to prove the principle of jet lift while in this country we have gone much more deeply into the safety and engineering problems associated with autostabilization. This work is proving the practicability of designing aircraft which under blind conditions can approach at a steep angle,

Table 2. The branches of the V.T.O.L./S.T.O.L. family



lose all speed at a height clear of obstructions and then let down gently to a vertical landing. Jet lift may one day be the answer to all-weather regularity and safety on the airlines.

More immediately it is required to give military aircraft freedom to operate without reliance on vulnerable runways. No other lifting system offers so small a performance penalty when installed in supersonic aircraft. Indeed it has been suggested that the penalty of installing jet lift may be less than the penalty of making the wing shape suitable for the low speed lift required for a normal take-off and landing.

Rocket Lift

This survey would not be complete without mention of rocket lift. If we assume three minutes as the jet-borne period required for take-off and landing, we find that the rocket engine plus its fuel weighs several times as much as the jet engine plus its fuel. The rocket is therefore no competitor to the jet for conventional aircraft.

For interplanetary or sub-orbital flight it is, however, the only known answer, both for launching and for deceleration prior to landing.

Conclusions

In the direct lift branch of the family (see *Table 2*) the primary consideration in determining the choice of the lifting system is cruising speed. This is almost paradoxical in that the lifting system, especially on the higher speed aircraft, is usually not used in cruising flight.

Table 3 gives the approximate speed brackets for the different types.

Table 3

	Design cruising speed
Simple helicopter	0 to 150 m.p.h.
Compound helicopter	125 to 250 m.p.h.
Convertiplane (Tilt Wing or Tilt Rotor)	125 to 350 m.p.h.
Ducted fan	300 to 650 m.p.h.
Pure jet	300 to 3000 m.p.h.
Rockets	above 6000 m.p.h.

A number of crossbreeds are possible and even probable, *e.g.*,

Deflected Slipstream	with Blown Flap
Deflected Slipstream	with Tilt Wing
Ground Cushion	with Jet Flap
Ground Cushion	with Jet Lift

Clearly there is no single or universal method of obtaining V.T.O.L. Wings are of different shapes to suit different speeds and powered lift must similarly change its shape to suit the speed.

The history of aviation is a steady progress to higher speeds so the future emphasis is likely to be on methods, such as jet lift, which are free from built-in speed restrictions.

Thanks are due to Mr C. H. R. Griggs for the illustrations.

1960 ESSAY COMPETITION FOR SCHOOLS

THE *Research* Essay Competition for Schools was instituted in 1957 with the purpose of encouraging scientifically-minded school pupils to write clearly and comprehensibly about their work; thus it was hoped to assist in raising the standard of the writing of scientific reports in the future.

The 1960 competition has reverted to its original form. Schoolboys and schoolgirls are asked to write a report of 1000 to 1500 words on any recent piece of practical work or special project they have carried out in chemistry, physics or biology. The author of the best report, in the opinion of the judges, will receive a prize of books to the value of £15 and there will be a second prize of books to the value of £10. In addition, books to the value of £15 and £10 will be awarded to the school libraries of the first and second prize winners respectively.

Full details of this competition are available from the publishers of *Research*, 4 and 5 Bell Yard, London, W.C.2.

THE ELECTRON THEORY OF METALS

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The development of the electron theory of metals is qualitatively described. It is shown how the failures of early theories, *e.g.* Drude–Lorentz and Sommerfeld, led naturally to the application of wave mechanical principles. The modern theory is used to explain simple properties—conductance, semiconductors and theory of alloys. The transition metals and more difficult problems are not discussed; the main difficulty in the subject is attributed to difficulty of mathematics.

THE modern theory of the metallic state has been developed over the past fifty years from a study of the crystal structures of metals and the electronic structures of metal atoms in the gaseous and solid states. Initially, theorists were content to explain only the characteristically high thermal and electrical conductivities of metals, but in recent years an attempt has been made to explain many more phenomena. Ultimately it is hoped that it will be possible to predict all the properties of metals and alloys from a knowledge of their constituent atoms. The development of the theory to its present state has necessitated several changes in basic physical concepts, and this development is most conveniently, although not chronologically, followed from the theory of the atom.

Originally the atom was considered as consisting of a central positively charged nucleus with a system of negatively charged electrons revolving around it. Dynamic equilibrium was maintained between centrifugal force and the electrostatic attraction. The motion of the electrons was thus completely described in terms of classical mechanics. This led to several difficulties; for example in this concept of the atom no one orbit was any more probable than another, yet the discrete lines which are observed in atomic spectra are contradictory to the idea of a continuous series of permissible orbits. BOHR, by a purely arbitrary assumption regarding the selection of possible energy levels, was able to explain simple spectra. He postulated that the electrons could only move in orbits 'stationary states' for which the angular momentum was an integral multiple of $h/2\pi$. Energy was absorbed or emitted in quantra only when an electron moved from one stationary state to another.

DE BROGLIE and SCHRÖDINGER, from mathematical reasoning, postulated that the electron, which has previously been regarded only as a charged particle, should exhibit the properties of waves. This in effect expressed the realization that one could not measure two conjugate physical properties, *e.g.* momentum and position, of very small particles simultaneously. The behaviour of the electron was then described mathematically by an equation which had the form of a wave equation. The original picture of the atom is, therefore, replaced by the picture of a nucleus surrounded by diffuse clouds of electrons. The probability of finding an electron at a given point is determined by solving the wave equation.

Drude–Lorentz Theory

The earliest theory of the metallic state was formulated at the beginning of this century by DRUDE and LORENTZ. A metal was assumed to consist of an ordered array of metal ions permeated by a gas of outer valence electrons. By the application of classical mechanics to the motion of the electrons, Drude and Lorentz predicted the Wiedemann–Franz law. This law, which stated that the ratio of thermal conductivity to electrical conductivity at a particular temperature was a constant, had been known for some time. Its theoretical prediction was a notable success and indicated that electrons could, to a first approximation, be considered free. There were naturally several difficulties with the Drude–Lorentz theory. It could not explain properly the way in which the electrical conductivity varied with temperature. In addition to this, the specific heat of such a model would be much higher than is actually the case. This latter difficulty was serious. It arose from assuming that the metal consisted of two distinct parts: a lattice of ions and an electron gas. From the theory of lattice specific heats, the value of the gram-atomic heat for the metal lattice should attain $3R$, where R is the gas constant. Similarly, if the free electrons obey the ordinary gas laws, their contribution to the total specific heat should be $3R/2$. The total specific heat, therefore, would be $9R/2$. DULONG and PETIT's law, however, which was deduced from experimental evidence, showed that the total specific heat does not rise above 6·3 cal/g atom, that is, above $3R$.

Sommerfeld Theory

It was not until 1928 that SOMMERFELD improved upon the Drude–Lorentz theory by applying the laws of quantum mechanics to the motion of the electrons. As with the Drude–Lorentz theory he assumed that the electrons were free but able to exist only in certain energy states determined by quantum theory. The possible energy states, unlike the energy states in a free atom, were very closely spaced because of the interaction of the atoms. Each of these energy states, according to the Pauli Exclusion Principle, could not contain more than two electrons. In its most primitive form this principle states that no two electrons can be described by the same wave function. The reason that two electrons rather than one can occupy the same energy level is that electrons have an internal degree of freedom. Even after the position and momentum of the electron have been determined as far as possible, the electron may be in one of two states, which differ as a rule only very slightly in their energy. The situation can be imagined by assigning a small magnetic dipole or spin to each electron which can have two different orientations. Magnetic effects are usually small and so the spin will not affect the energy greatly, although in some cases measurements of magnetic susceptibility permit conclusions concerning the spin. Two electrons can be in the same orbit if they differ in orientation of their spins and so are in reality in different states.

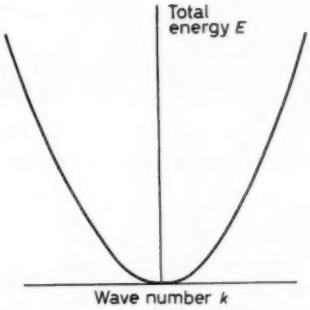

Figure 1. The relation between energy (E) and wave number (k) for a free electron. Strictly the curve applies to the motion of an electron in one direction only, but in the Sommerfeld theory all directions are equivalent and similar curves are thus obtained

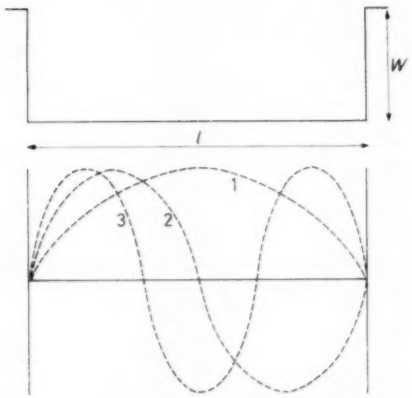

Figure 2. Diagram illustrating the possible wavelengths fitting into the potential box; n is 1, 2, 3 for curves, 1, 2, 3 respectively. (After COTTRELL[2]*)*

It can be shown that for a free electron the wavelength is given by,

$$\lambda = h/mv$$

where m is the mass of the electron and v its velocity. It is customary to use the wave number, k, where

$$k = 2\pi/\lambda \text{ (number of waves/unit length)}$$

The wave number is a vector quantity, describing the direction of wave propagation in addition to the number of waves per unit length. The kinetic energy of a free electron is given by the relationship,

$$E = \tfrac{1}{2}mv^2$$

substituting for v,

$$E = h^2k^2/8\pi^2m$$

thus a plot of E as a function of k is a parabola (*Figure 1*). The kinetic energy of an electron may be regarded as a measure of its total energy, as for a free electron the potential energy is to a first approximation constant, and so may be regarded as zero. The only effect of this assumption is to displace the zero of the E/k curve. The curve is strictly quasi-continuous but for a massive piece of metal the points are very close together.

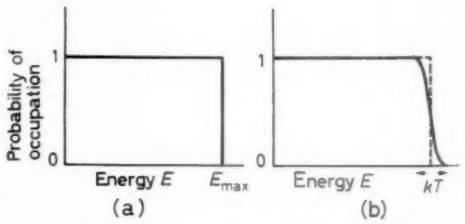

Figure 3. Fermi distribution curve: (a) at the absolute zero of temperature; (b) at T°K

Only certain solutions of the wave equation are acceptable, for example the solutions must be finite, single-valued, and continuous. Such solutions are usually sine or cosine functions, or more generally,

$$\mu_{(x)} = e^{2\pi ix/\lambda}$$

where $\mu_{(x)}$ is a symbol denoting the wave function, and $i = \sqrt{-1}$. To understand the motion of electrons in a three dimensional metal lattice it is simplest to consider first a single electron in a one dimensional piece of metal, length x. The attraction of the metal lattice for this electron is equivalent to saying that the electron is prevented from leaving the metal by a potential barrier, height W. This is schematically represented as a potential box of length x and height W (*Figure 2*).

The permissible solutions of the wave equation are those which can be fitted into this potential box. The electron cannot have a finite value of ψ outside the box for this means that the electron has a definite probability of appearing outside the metal. Therefore the sinusoidal probability curves must fall to a zero value at the boundaries of the box, and since ψ must be continuous, this is only possible for wavelengths such that nodes occur at the boundaries of the box.

Where n is an integer $\lambda = 2l/n$. Therefore since $E = \frac{1}{2}\, mv^2$ and $v = h/\lambda m$, the permissible energies are given by,

$$E = 1\ (h)^2/2m\ (\lambda)^2$$
$$= n^2h^2/8ml^2$$

Extending this to a cubically shaped three dimensional metal the equation becomes,

$$E = (h^2/8ml^2)(n_x^2 + n_y^2 + n_z^2)$$

This equation defines the permissible energy states for a three dimensional metal.

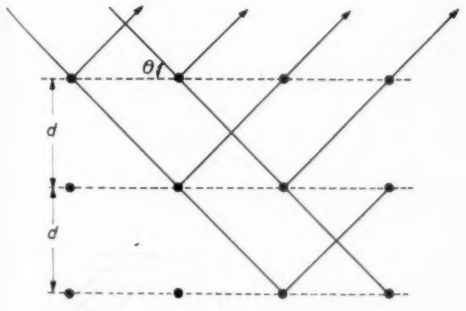

Figure 4. Diagram showing the diffraction of an electron beam by a crystal lattice of interplanar spacing d

The next problem is to consider which states are occupied. SOMMERFELD considered that the energy levels in the metal were occupied by electrons in accordance with the Pauli principle. At the absolute zero of temperature a number of valence electrons N occupy the $N/2$ lowest energy states, up to E_{max}, and all higher levels are completely empty. On a two dimensional scale the boundary of occupied

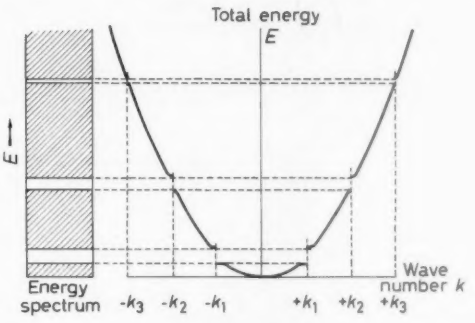

Figure 5. Modified curve showing the variation of total energy with wave number for electrons moving in a particular direction through a crystal

states is a circle, but on a three dimensional basis it is a sphere, called the *Fermi* sphere. The non-valence electrons are virtually unaffected by the metallic bond and may be considered to belong to the individual atoms. The valence electrons, however, are rearranged in a number of energy levels. Since an electron can move only into a vacant quantum state, all thermally excited electrons must be excited into states above E_{max}. The thermal energy available for any electron at a temperature T°K is of magnitude kT, where k is Boltzmann's constant, $1{\cdot}38 \times 10^{-16}$ ergs per degree, and consequently only those electrons having energies between $(E_{max} - kT)$ and E_{max} can be thermally excited. At normal temperatures E_{max} is much larger than kT so that only a small proportion of the free electrons can absorb thermal energy and the specific heat contribution of the free electron gas is extremely small (*Figure 3*). The replacement of classical mechanics by quantum mechanics enabled Sommerfeld to show why the electron did not contribute largely to the specific heat, but the theory was still unable to explain many other phenomena, for example the difference between conductors and insulators, or the cause of magnetic properties.

The Zone Theory

The conclusions of the Sommerfeld theory were reached on the assumption that the electron was perfectly free, that is, a uniform potential field existed within the block of metal. In actual fact, the potential field in the metal is periodic with

the period of the crystal structure and this field influences the movement of the electrons. If a beam of electrons of wave length λ impinges on a set of crystal planes of inter-planar spacing d, such that Bragg's law is obeyed, that is

$$n\lambda = 2d \sin \theta,$$

it is reflected. Thus electrons with an energy corresponding to λ cannot move in a direction θ.

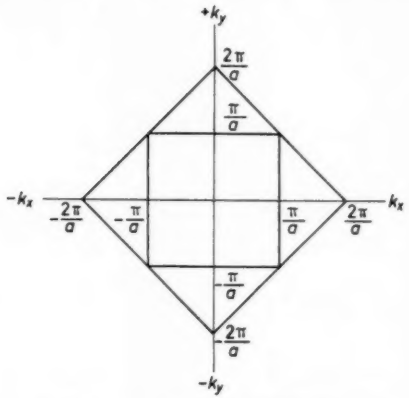

Figure 6. The first and second Brillouin zones for a two dimensional simple cubic lattice

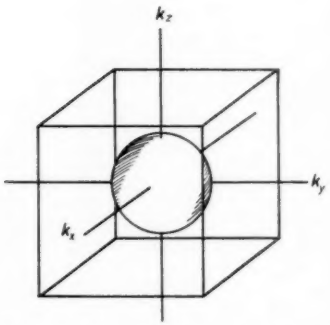

Figure 7. First Brillouin zone for a three dimensional simple cubic lattice. The Fermi sphere encloses the occupied states for a half filled zone

This relationship is true for waves moving within the crystal as well as those striking the crystal from outside. This has the effect of modifying the parabolic relationship between energy and wave number and the curve in *Figure 5* is obtained.

The energy gaps represent the range of energies which an electron cannot possess if it is to be free to move in this direction in the lattice. Similar curves apply to other directions of motion in the lattice but the position and magnitude of the energy gaps are different. The values of k at which these discontinuities occur are calculated from Bragg's law as follows: reflections from a set of planes of inter-planar spacing a occur for electrons of wavelength λ if,

$$\lambda = 2a \sin \theta/n$$

where n is the order of reflection and θ is the angle of incidence. Since k, is defined as $2\pi/\lambda$, critical values of the wave number k are given by,

$$k = \pm \pi/a \sin \theta$$

considering first order reflections only. Consider the simple case of a two dimensional cubic lattice: an electron moving in an x or y direction will be diffracted when $\lambda = 2a \sin 90°$, thus the first critical value of k is π/a. The electron also encounters rows of atoms which can be considered as diagonal atomic planes with spacing $a/\sqrt{2}$ and diffraction occurs when $\lambda = 2a/2 \sin 45°$. Thus there will be a second critical value at $2\pi/a$. When the electron is moving diagonally, that is at 45° to x and y it encounters planes of spacing $a/\sqrt{2}$ at 90° and planes of spacing a at 45°. In both cases the critical value of k is $2\pi/a$. This treatment can be continued and if a simple plot is made it is found that the critical values lie along straight lines which are parallel to the planes which caused the discontinuity. The zones bounded by these straight lines are termed Brillouin zones. The Brillouin zone is only a graphical construction in k space and is in no way a part of the crystal structure. The size and shape of the zones are determined solely by the crystal structure. The zone is easily extended to three dimensions when the lines become planes.

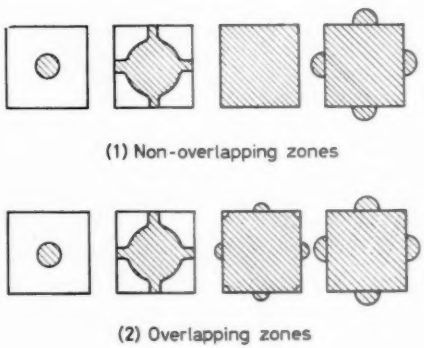

Figure 8. Various stages in the occupation of a two dimensional Brillouin zone (left to right) by electrons. (After COTTRELL[2]*)*

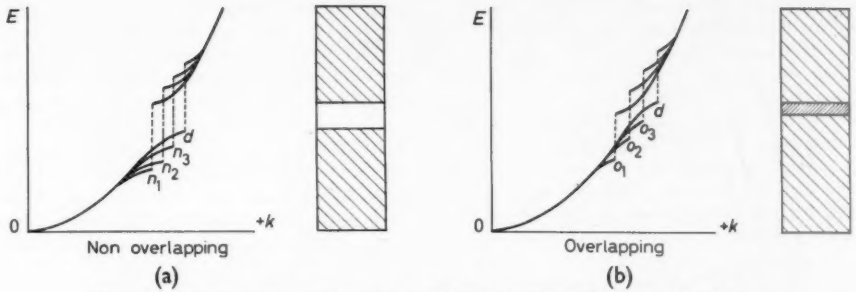

Figure 9. Superimposed E|k curves for different directions illustrating the formation of (a) *energy gaps* (b) *overlapping zones. Different directions are signified by 1, 2, 3 . . . d; d is the diagonal and this represents the direction of greatest deviation*

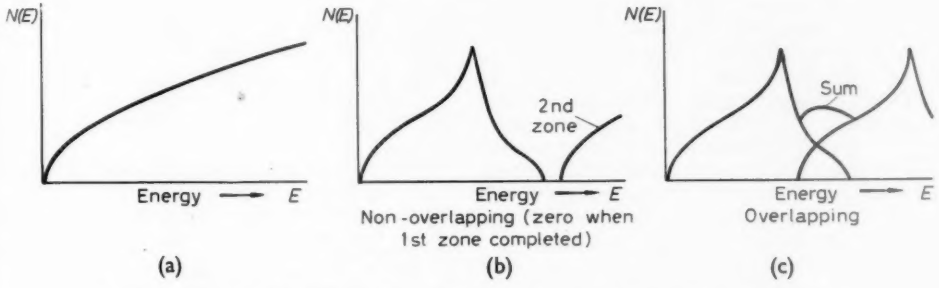

Figure 10. The relationship between density of states and energy: (a) *according to the Sommerfeld theory;* (b) *non-overlapping zones in an actual crystal;* (c) *overlapping zones in an actual crystal*

In the wave number diagram (*Figure 7*), the occupied states form a sphere round the origin. As more states are occupied, and the planes of the Brillouin zones are approached, the sphere is distorted. The various stages in the occupation of a two dimensional Brillouin zone by electrons are illustrated in *Figure 8*. The first case represents non-overlapping zones, and here the first zone must be fully occupied before any electrons start to enter the second zone. Two zones are non-overlapping when all the energy levels of the first zone lie lower than any in the second zone. In other words the energy spectrum is as in *Figure 9a* irrespective of the direction of movement of the electrons. All directions are not equivalent and it is possible that certain directions in one zone will possess higher energies than the lowest in another and the zones are said to overlap. How this occurs is illustrated in *Figure 9b*. In the case of overlapping zones, the filling of the second zone commences before the first is completed, and in this case there will always be partially filled zones in the crystal no matter what the electron concentration is.

Often it is necessary to know the distribution or density of electron energies within any given range in the energy spectrum. For example, in some crystals most of the energy states occur towards the lower end of the energy spectrum, whereas in others there may be only a few levels in this region. The density of states is defined as $N(E)$, where $N(E)\mathrm{d}E$ is equal to the number of quantum states per unit volume of the crystal with energies in the range E to $(E+\mathrm{d}E)$. In the Sommerfeld theory the relationship between $N(E)$ and E is a simple parabola, (*Figure 10a*), but in actual crystals this is modified by Brillouin zones (*Figure 10b*). The overlapping of zones makes the form of the $N(E)$ curve very complicated in the higher energy ranges. In such cases the complete $N(E)$ curve is given by the sum of the individual curves for each zone in the region where the overlap occurs (*Figure 10c*).

The zone theory has the advantage over earlier theories in that it can be applied to metals and non-metals, as the electrons are considered free in both cases. The use of the theory will now be illustrated

by application to various problems, for example, conduction and insulation, semi-conductors, and the theory of alloys.

Order–Disorder Changes

It was originally assumed that the difference between conductors and non-conductors was that in the former the electrons were free whereas in the latter they were fixed. The relatively stronger electron binding in an insulator can account for an increase in resistance of only 100 times, and not 10^{10} to 10^{24} as is observed. Now according to the zone theory, all the valence electrons in a solid are free to move through the lattice. Electrical resistance is considered to be the result of interaction of these electrons with the crystal lattice. Under normal conditions as many electrons are reflected in one direction as in another and there is no net flow in any direction. However when a potential is applied across the x direction (as in *Figure 11*), a net flow of electrons along the x direction is obtained. All the electrons participate in the conduction and all are accelerated. The sphere of occupied space in k space is shifted and although the electrons interact with the lattice and some are reflected, a uniform flow, representing a current, is obtained. In other words, only the electrons near the origin in k space cancel each other out.

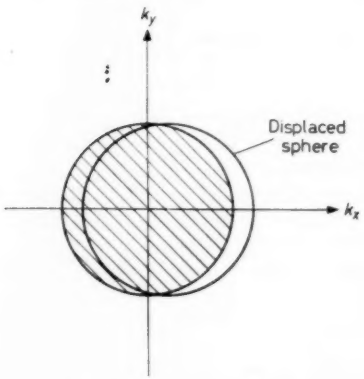

Figure 11. A two dimensional representation of the Fermi sphere of occupied states in k space. The sphere is displaced by the applied potential

When the first Brillouin zone is nearly complete, or rather when the Fermi surface is approaching a Brillouin plane, the potential field may accelerate the electron into an energy range which is not permitted in its particular direction and so it is reflected. This reflection of electrons with a particular energy was the criterion upon which the zone theory was based. This additional reflection increases the resistance further. A perfectly regular lattice, which does not vibrate, for example at the absolute zero of

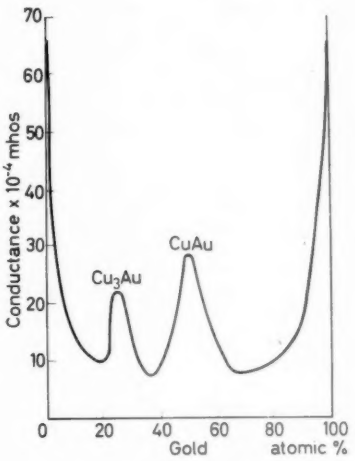

Figure 12. The graph of conductance against atomic percentage of gold for copper–gold alloys showing an increase in conductance on ordering (at 25 per cent and 50 per cent gold). (After KURNAKOW, ZEMCZUZNY and ZASEDATALER *J. Inst. Metals* (1916) **15**, 305)

temperature, should on the wave mechanical theory offer no resistance to the motion of an electron. This is difficult to appreciate if resistance is visualized as collisions of particles with the lattice, but if the lattice is perfectly regular with a periodicity greater than the wavelength of the electron, then it is possible for a wave propagation to move through it without interaction with the lattice points. In practice, however, crystal lattices are never perfectly regular and possess thermal vibrations. Any further irregularities introduced by working, alloying, or increasing the temperature will increase the effective scattering power of the lattice and hence increase the resistance. In an ordinary solid solution the different species of atoms are arranged at random on the atomic positions of the lattice but there are many solid solutions in which another atom configuration occurs. Atoms of one kind segregate more or less completely on to one set of atomic positions. The resulting arrangement can be described as a lattice of A atoms interpenetrating a lattice of B atoms. This segregation takes place with little or no deformation of the lattice, creating

an ordered solid solution, or ' superlattice ', out of a random solid solution. The formation takes place at relatively low temperatures and at compositions expressed by simple formulae like AB or AB_3. The usual randomness persists at all temperatures above a certain critical temperature; when the temperature is lowered through the critical point order sets in and increases as the temperature is further decreased, approaching perfection only at low temperatures. The progress of an order–disorder change can be conveniently followed by resistance measurements. When the disordered alloy becomes ordered there is an increase in the conductance, since the interaction of the electrons with the lattice is decreased, for example, copper–gold alloys (*Figure 12*).

Conductance

Since conduction relies upon the fact that vacant states are available into which the electrons can be accelerated, only materials possessing partially filled zones can conduct. If a potential is applied to a material consisting entirely of completely filled zones, no electrons can be accelerated and consequently no current flows. The breakdown potential of such a material is the energy required to lift the electrons from the filled zone, across the energy gap into the next zone where they can conduct.

Semi-conductors are in general characterized by the fact that their electrical conductivity is increased by a rise of temperature and by the presence of impurities in contrast to the behaviour of normal metals. They can be classified according to whether or not they are dependent on the presence of impurities for their conducting properties. The *intrinsic* semi-conductor is an insulator at 0°K but at normal temperatures, because of the small energy gap between zones, some electrons are excited into the next zone where conduction can then occur (*Figure 13a*). The electron ' holes ' left in the first zone by the removal of electrons to the second zone also contribute to the conduction; this is known as *positive hole conduction*. Increasing the temperature increases the number of electrons and holes available for conduction and this more than compensates the increase in resistance due to increased thermal vibration of the lattice. Conduction by the majority of semi-conductors, however, is greatly affected by the presence of impurities. When impurity energy levels are present in the semi-conductor its behaviour is determined by the position of these levels with relation to the energy gaps. If the impurity levels are actually in the zones then the semi-conductor will conduct at all temperatures and will to some extent be temperature independent. If the impurity levels are in the energy gap, the semi-conductor will conduct only when sufficient thermal energy is available to excite the electrons into another level. An incomplete impurity level in or near the first zone will accept electrons from this zone, permitting limited hole conduction by the zone. A complete impurity level in or near the second zone will donate electrons to this zone, and these electrons are then available for conduction (*Figures 13b* and *13c*).

Theory of Alloys

The zone theory can also be applied to the theory of alloys and successfully explains the importance of electron concentration on stability of phases. From

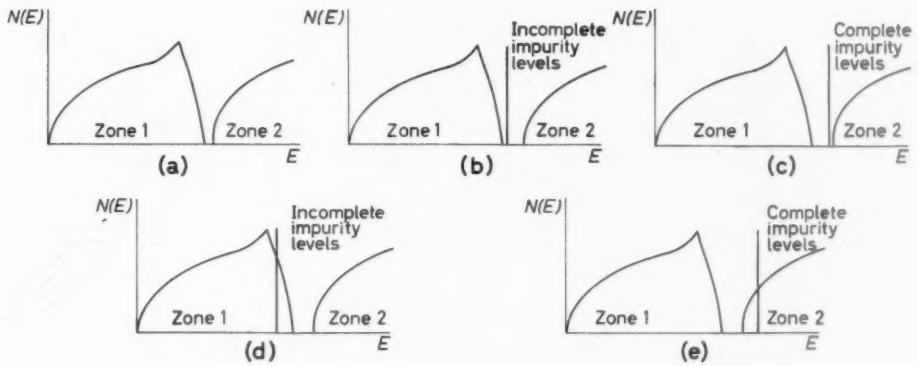

Figure 13. N(E) curves for (a) *intrinsic, temperature dependent semi-conductors;* (b) *and* (c) *impurity dependent, temperature dependent semi-conductors;* (d) *and* (e) *impurity dependent, temperature independent semi-conductors*

experimental evidence, HUME-ROTHERY recognized that the controlling factor in the formation and composition of alloy phases is the electron concentration, although its effect is often masked by other effects, for example electrochemical and atomic

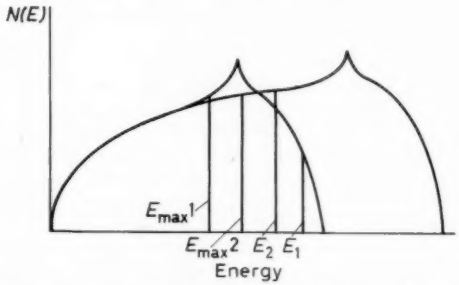

Figure 14. N(E) curves for two different structures showing how when the electron concentration is altered one structure becomes unstable relative to the other

radii differences. In many alloys of copper, silver or gold with metals of higher valency, similar phases occur at similar electron concentrations. For example many elements form solid solutions with copper up to 1·4 electrons per atom (e/a) and other phase changes occur at 3/2, 21/13 and 7/4 e/a.

The first Brillouin zone of a face-centred cubic metal can be shown to hold no more than two electrons per atom. Since the normal monovalent metal has only one electron per atom to contribute, this zone is only half full. The effect of other elements will depend upon their valency. For example, the addition of divalent zinc to monovalent copper will increase the electron concentration. Considering the $N(E)$ curve for copper: if the electron concentration is increased E_{max} will increase slowly and steadily as there are many states available, but once the peak has been passed E_{max} will increase rapidly and the structure will become unstable very quickly compared with another structure which can still accommodate electrons easily. The steeper the fall from the peak, the more quickly the structure becomes unstable. Considering the $N(E)$ curves for two different structures at the same e/a (*Figure 14*) structure 1 is more favourable than 2 but when the peak of 1 has been passed E_{max} increases rapidly and 2 becomes more favourable. The electron concentration at the peak of the $N(E)$ curve is 1·36 e/a for a face-centred cubic metal. The corresponding value for a body-centred cubic metal is 1·48 e/a. Thus a face-centred cubic structure becomes unstable at 1·36 e/a and a body-centred cubic structure at 1·48 e/a. The theory is unable to predict a structure from a knowledge of the constituent atoms; for example it is unable to explain why copper should be face-centred cubic.

Transition Metals

The zone theory is also able to give a limited explanation of the complicated behaviour of the transition metals, for example, ferromagnetism and high cohesive strength, but is unable to give a complete explanation of any phenomenon because of the simplifying assumptions which have to be made. For example the precise nature of the potential field due to the lattice is not known and varies from substance to substance. It is generally assumed to be periodic with the periodicity of the lattice but the presence of impurity atoms disturbs this periodicity and the effect of such atoms can only be estimated. The electrons interact with each other in some way and a crude approximation of this effect is included in the expression for the general field of force. The use of wave mechanics involves some fundamental approximations which are necessary to permit solution of the wave equation. The mathematics involved in wave mechanics is very difficult and research is required to permit the solution of more complex problems. With the further development of this method of mathematical manipulation, a more rigorous approach to the electron theory of metals will be available.

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MICROMINIATURIZATION OF ELECTRONIC EQUIPMENT

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Since the introduction of the transistor it has become possible to reduce the size and volume of electronic equipment considerably. Three systems of miniaturizing are described—micromodule, micro-circuit and solid circuit. Methods of fabricating these microminiature electronic assemblies are given, and also a table showing packing densities of components possible in these techniques. This is the fourth article in the series on *Microinstruments*.

CONSTRUCTIONAL techniques of electronic equipment generally follow component design, and the normal metal chassis, still widely used, has standard components mounted on tag-boards or stand-off insulators. This construction is being replaced to a large extent by printed wiring boards on which components are mounted with the board forming its own insulating chassis. The use of transistors and sub-miniature components in conjunction with printed wiring boards has resulted in still smaller constructions, and components are now being developed in which the size has been reduced to almost the ultimate whilst retaining conventional shapes, methods of attachment, end contacts, *etc.*

Even with this type of construction it is surprising how low the effective packaging efficiency is—mainly because of cooling requirements, withdrawal space for units and accessibility space for repairs. A typical sub-miniature intermediate frequency amplifier when fitted in an equipment has a ratio of about three parts air to one part electronics, that is, the component packaging efficiency is about 25 per cent. The important point, however, is that with present shapes of sub-miniature components it is not possible to pack more components into a given space because of the difficulties of soldering them in (even with miniature soldering irons) and still provide adequate accessibility for repair. It could be said that the limit of miniaturization with this type of construction has been reached. The next logical step in development is to use film components in which the actual working element only is used.

In any typical tubular component most of the available volume is taken up by material which plays no part in its electrical performance. In a cracked carbon resistor the active film element has a volume of approximately one five hundredth of the total component volume. Similarly, in a ceramic fixed capacitor about one two hundred and fiftieth of the volume is effective, the remainder consisting of ceramic tube, case and connections. These ratios are illustrated in *Figure 1*.

The heat dissipation of the cylindrically shaped component is inefficient because of the low surface area to volume ratio and an increase in power loading (or a reduction in effective size) could be made by opening out the cylinder and its leads into flat strips provided sound connections to the films are made. The comparatively large end connections on tubular components could thus be obviated and to a certain extent component protection techniques may be reduced and the unit protected as a whole.

The miniaturization problem is, of course, aided by the low voltage requirements of the transistor components. Because of these low operating voltages and for low power ratings, it now becomes possible to design components using extremely thin films of resistive, capacitative, conductive, magnetic or semi-conductive materials. Resistors can be made of films evaporated from metal alloys such as nickel–chromium, with end connections of evaporated nickel. They can also be made in film form in platinum–gold alloys, chemically deposited and subsequently fired, with soldered end connections, or in tin–antimony oxide with fired or evaporated end connections. All of these show high potential reliability. Capacitors can be formed of thin films of high dielectric constant material, of tantalum oxide and by dielectric evaporation techniques, using materials such as silicon monoxide, and also by the use of very thin plastic films. Magnetic films can be made by evaporation techniques in a strong magnetic field, using materials such as nickel–iron alloys. Conductive films can be evaporated from copper or from noble metals through masks to form any required wiring pattern.

The use of film components leads to 'microminiature' techniques and it would be useful at this stage to consider the possible packing densities of components in electronic equipments. *Table 1* below shows typical packing densities in terms of the number of components which can be packed into one cubic foot of equipment. This is not strictly accurate since it does not include cooling or

inter-connection requirements, but it is commonly used as a method of comparison. This table shows that there is a large increase in packing density from valves to transistors, but an even larger increase from transistor constructions to microminiature constructions.

Table 1. Packing density of equipment

	Components/ft³
Normal valve construction	1000–5000
Miniature valve construction	3000–10,000
Sub-miniature valve construction	10,000–15,000
Normal transistor construction	30,000–40,000
Transistor with sub-miniature components	50,000–60,000
Micromodule construction	500,000–600,000
Microcircuit construction	1,500,000–3,000,000
Solid circuit construction	30,000,000–50,000,000

There are three main systems in microminiaturization techniques—micromodules, micro-circuits and solid circuits. Each of these will be described briefly.

Micromodular Systems

This conception was introduced by the U.S. Army Signal Corps and is being manufactured by R.C.A. in association with many subcontractors. Film components are used on individual ceramic or glass plates only 0·3 in. by 0·3 in. and about 0·01 in. thick. These individual components, called *microelements* are then stacked one above the other and connected together by *riser* wires at the sides of the microelements. Some typical elements and an assembly, together with a typical construction of an equipment, are shown in *Figures 2* and *3*.

The main advantage of this system is that as the components are made separately they can be individually tested so that only good components are used in assembly. In other systems, many components are formed simultaneously, or nearly so, so that the process control must be very good indeed if the total reject rate is to be kept down.

The system has been designed primarily for radio receivers and many circuits have been fabricated covering radio frequency amplifiers, mixers, intermediate frequency amplifiers, limiters, audio frequency amplifiers, *etc*. Some typical circuits are shown in *Figure 4*, together with the actual micromodules from which the size can be seen.

Micro-circuit Systems

The basic difference between the micromodular system previously described and the micro-circuit approach is that a complete circuit is made on a small plate, rather than individual components. The size of the circuit is determined mainly by the reject rate

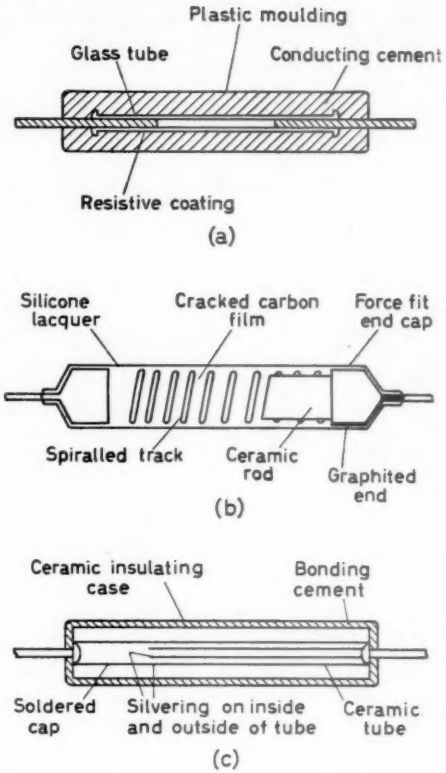


Figure 1. Active and non-active volume of typical components: (a) *Grade 2 insulated resistor;* (b) *Grade 1 non-insulated resistor;* (c) *Ceramic capacitor*

	Volume of active element: ft³	*Total volume: ft³*	*Fraction: used/unused*
(a)	~ 0·00025	0·09	~ 1/280
(b)	~ 0·00005	0·027	~ 1/540
(c)	~ 0·003	0·675	~ 1/225

in processing the components, but the intention is to place a circuit function, *i.e.* a multi-vibrator, a single stage amplifier, a single stage oscillator, *etc*., on one small plate. The size of the plate will vary but most simple circuits can be placed on a plate ½ in. by ½ in. In some cases units of 1 in. by 1 in. will be made.

A typical emitter coupled multi-vibrator circuit is shown in *Figure 5* which shows the size of the unit.

Preparation of Microminiature Circuits

First a glass substrate is prepared of the correct size, usually 0·6 in. by 0·6 in. (to allow an edge) by

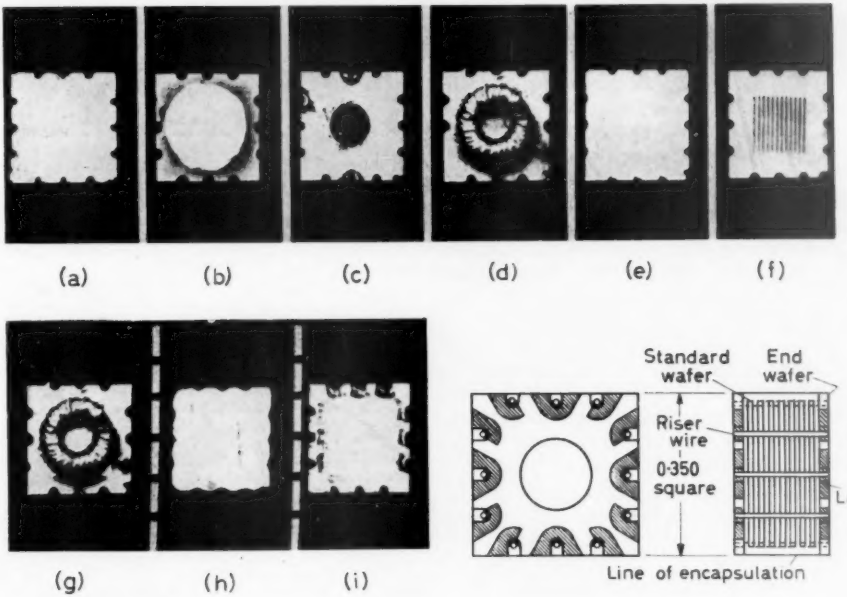


Figure 2. Typical microelements and micromodule. (*By courtesy of the Radio Corporation of America*)

(a) Crystals: quartz crystal for operation at 45·1 mc; (b) Transistors: prototype transistor type 2N404; (c) Diodes: silicon diode type 1N277; (d) Inductors: temperature stabilized ferrite core inductor up to 1·5 millihenries; (e) Capacitors: multi-layer thin film precision type up to 1350 uuf; (f) Resistors: metal oxide film type up to 180,000 ohms; (g) LC Combination: ferrite core inductor mounted on a ceramic capacitor; (h) RC Combination: multi-layer ceramic capacitor with deposited thin metallic film resistor; (i) Multi-resistor: thin metallic film type four resistors, $\frac{1}{8}$ watt per resistor. (The last three are multiple elements.)

0·1 in., and carefully cleaned. Holes in the plate are then drilled ultrasonically for the insertion of the miniature transistors. The resistors are then formed by first evaporating copper over the surface and etching a negative pattern of the required resistors in the copper, after which nichrome is evaporated. The unwanted copper is then etched away and resistors are left in the nichrome in the correct positions of approximately the correct values. Adjustments may be made by abrasive or other means, but this technique has yet to be perfected.

Capacitors can be made experimentally by evaporating dielectrics such as silicon monoxide and certain kinds of glass, but this again is in the experimental stage. It is possible to use films or plates of high permittivity ceramic material, which can be

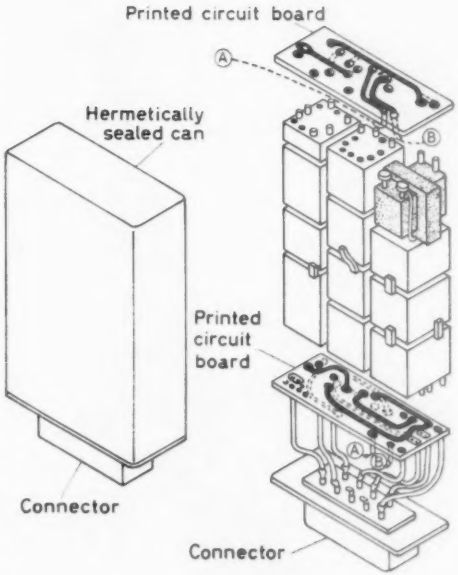


Figure 3. Typical assembly of micromodules. (*By courtesy of the Radio Corporation of America*)

inserted in a similar way to the transistors. The flat transistors are then inserted (the preparation of these will be dealt with in detail later), and finally the capacitor top electrodes and all the wiring is evaporated in gold through the copper mask. All masks are made of copper sheet using normal photo-mechanical printed circuit processing, but etched right through. The required wire pattern is first drawn on a large scale black and white drawing, which is photographed and reduced in size to form a negative. This negative is used for an exposure to ultra-violet light to harden off a coating of light-sensitive solution placed on it. When etched in ferric chloride the parts not protected by the resist are completely etched away. As this is a photo reduction process the accuracy can be very high indeed.

It is also possible to evaporate magnetic films by evaporating nickel iron in a strong magnetic field so that it is feasible to evaporate conducting lines, resistors, dielectrics, and also magnetic films experimentally where required.

This opens up possibilities in circuit design as it is comparatively easy to evaporate resistors on the surface of capacitors and *vice versa*, so that composite components may be formed with unusual characteristics. This avenue is being explored.

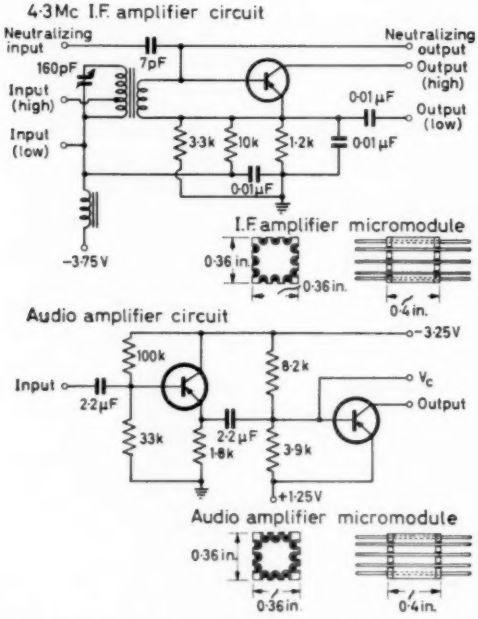


Figure 4. Typical micromodule circuit assemblies. (By courtesy of the Radio Corporation of America)

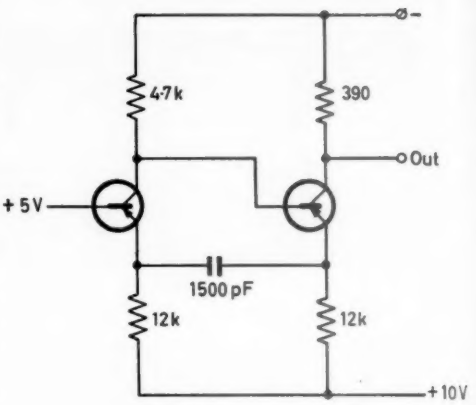


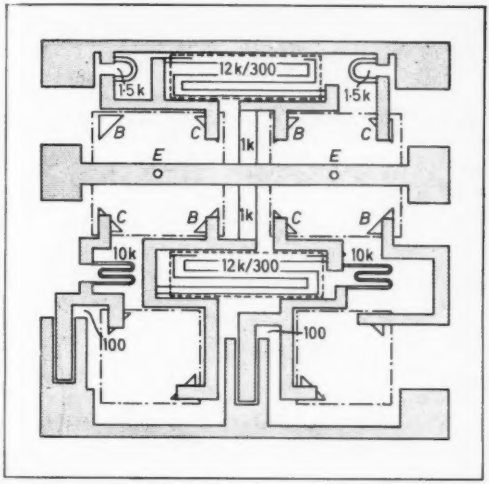
Figure 5. Emitter coupled multi-vibrator. (Crown copyright reserved)

Transistors are, of course, the key to all micro-miniaturization, and for use with the micro-circuit techniques a range of transistors is being developed in a circular shape fully sealed by ceramic or glass/metal techniques, in containers which are only 0·125 in. in diameter and approximately 0·04 in. deep. The number of leads or contacts on the upper surface has not yet been decided but will possibly be more than three in order to assist circuit layouts.

Figure 6 shows the more complicated layout and theoretical circuit diagram of a binary counter stage. In this case experimental square transistors and diodes were used because the circular fully sealed shapes were not available. It does, however, illustrate the number of components which can be placed on one side of a $\frac{1}{2}$ in. square plate, *i.e.* two transistors, two diodes, eight resistors and four capacitors in addition to the wiring.

Solid Circuits

This is the most promising of the three techniques from a long term point of view, as the basic principle is to form the circuit components—resistors,



capacitors, transistors, diodes, *etc.*, in a solid block of silicon. By suitably shaping the block, isolation may be obtained between the circuit elements so that there are no end connections between the various component functions. The reliability of such a device should be very high indeed, but there is a great deal of work to be done before obvious difficulties such as temperature coefficients, complete component isolation, *etc.*, can be effective. *Figure 7* shows some possible elements which can be made from materials such as silicon or germanium. The resistivity of silicon can vary from 0·001 to 300 ohms/cm, and by doping with certain heavy metals this range can be increased to 3000 ohms/cm, so that if a bar is cut and end connections made, the material itself can be used as a resistor. It is important to ensure that non-rectifying contacts are made by suitable techniques. The length, width and depth of the bar will control the actual resistance value for any given resistivity material. *Figure 8* shows a bridge of four resistors for a multi-vibrator circuit.

A capacitor can be formed (see *Figure 7b*) from silicon material as the P–N junction acts like a

Figure 6 (*Left*). *Binary counter circuit layout. Actual size—0·6 in².* (*Crown copyright reserved*)

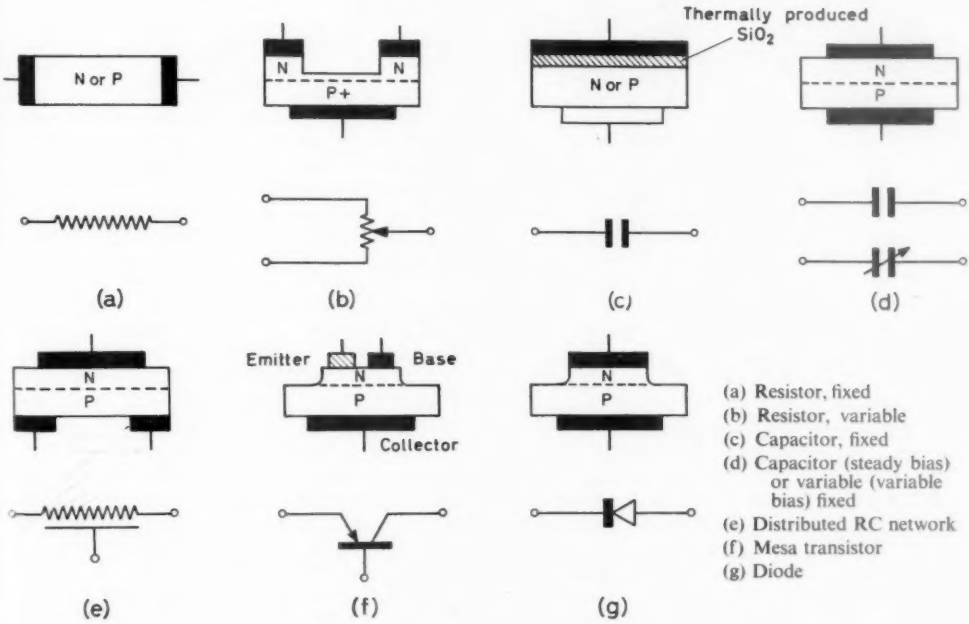
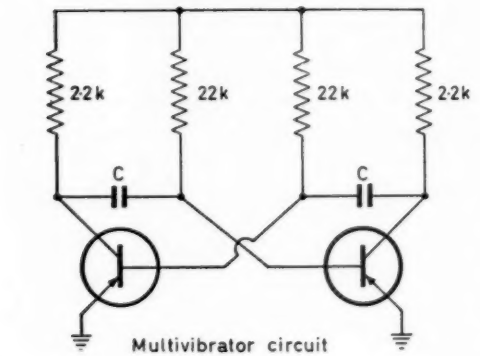


Figure 7. Solid circuit component elements

parallel flat capacitor with plates whose spacing is that of the width of the space charge layer. The dielectric constant of silicon is about twelve, but the width of the space charge layer at the junction and the resultant capacitance is a function of the applied voltage.

Fixed capacitors can be fabricated in the above way but variable capacitors can also be made by varying the bias voltage. Maximum to minimum capacitance ratios of as high as 15:1 can be obtained, although not all of this range is usable because of the breakdown voltage, voltage sensitivity and internal contact potential. As in the case of the evaporated capacitor deposited on an evaporated resistor, close coupling can also be obtained in the solid circuit elements as shown in *Figure 7c*. Transistors are formed in the normal way as Mesa type transistors and also diodes.

Working circuits of oscillators and multi-vibrators have already been made in the U.S.A. by Texas Instruments, and *Figure 9* shows the construction of a multi-vibrator together with the circuit



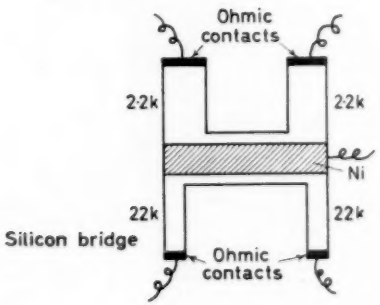


Figure 8. Silicon resistors for multi-vibrator circuit

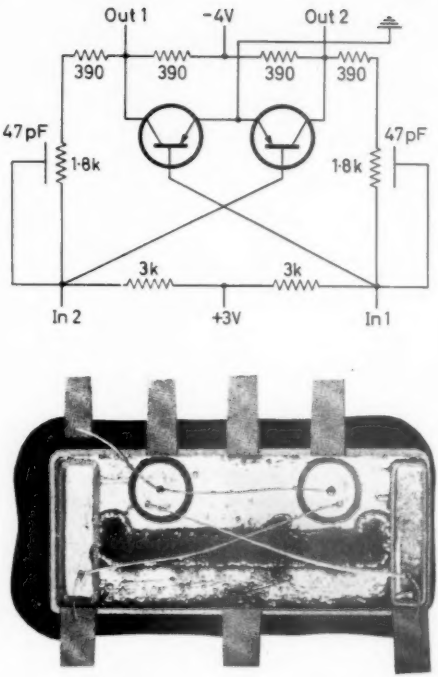


Figure 9. Multi-vibrator circuit and solid unit (approx. 0·24 in. by 0·12 in. by 0·25 in.) (By courtesy of Texas Instruments Ltd)

from which it has been derived. The size is approximately ¼ in. by ¼ in. by 1/10 in. and the resistors are isolated in this case by cutting a slot in the material, which can clearly be seen between two transistors on the top of the diagram and the three leads at the bottom. The three leads at the bottom are for the two 3000 ohm resistors with the centre tap. The shaded areas above the left and right hand bottom contacts are plated contacts on back biased junction capacitors, whilst the four contacts on the top sub-divide the four 390 ohm resistors between each contact. The two Mesa type transistors can clearly be seen as circles and the cross wires used to interconnect some of the circuit are also shown.

It will be seen that it is possible to obtain resistors, capacitors, transistors and diodes to form circuit elements and it has recently been discovered that inductive effects may be also obtained in these solid circuit techniques. The future, therefore, for this type of construction looks extremely bright, but it must be emphasized that considerable time will have to elapse before the present difficulties can be overcome and the overall reliability estimated.

PROCESSING BY IRRADIATION

II—Application to Food Preservation

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The chemical changes induced in food by radiation treatment are considered with regard to effect on quality and on nutritive value and possible toxicity.
(*Processing by Irradiation, Part I—Sterilization of Medical and Pharmaceutical Products*, was published in the April issue of *Research*, page 151)

THERE is no doubt about the effectiveness of ionizing radiation in destroying the bacteria, yeasts, moulds, parasites and insect pests which play a large part in the deterioration of stored foods. However, unlike the application of a radiation process to the sterilization of certain medical products, as described in *Part I*, its application to food preservation presents serious problems concerning induced chemical changes in the material being treated. Irradiation, like heat, causes some chemical changes in foods, and the extent and significance of these changes must be critically examined. Their influence on quality and hence consumer acceptability will, apart from economic and technical considerations, determine feasibility, whilst a clear demonstration that nutritive value is not unduly impaired and that no toxic products or carcinogens are formed will be the ultimate criterion of the practicability of this new process.

The potential of radiation in food preservation has already been extensively explored[1] and the dose levels required for the different applications envisaged have been determined (*Table 1*). The amount of induced chemical change is small at all levels but it increases with increasing dose so that, particularly when effect on quality is being considered, low dose processes are likely to be the most successful.

Table 1. Dose levels required for various food applications

Application	*Cause of spoilage*	*Dose (Mrad)*
Storage of meats (sterilization)	Bacteria (*Cl. botulinum*)	3–5
Extended refrigeration life of meats, fish, *etc.* (pasteurization)	Bacteria (vegetative)	0·05–1
Fruit storage	Moulds	0·1–0·5
Safety of frozen egg	*Salmonella*	0·2–0·5
Disinfestation of grain	Insects	0·02
Storage of root crops	Sprouting	< 0·01
Elimination of parasites in meats	*Trichinella spiralis*, *etc.*	0·01

Possible Low Dose Applications

There is evidence that disinfestation of grain by γ-irradiation could be applied without adversely affecting the quality of the milled product. The baking properties of English wheat and the flavour of the baked products are only slightly altered[2] even up to a dose level of 0·5 Mrad. It appears also that *Salmonella* can be eliminated with a high degree of safety from frozen whole egg without impairing baking quality and no significant flavour change occurs in finished sponge cakes made from it[3]. Further tests on eggs are currently in progress and comparison is being made between the quality of the irradiated and the heat processed material. An irradiation process would have the obvious advantage over heat processing in that it can be applied to the egg while in the frozen state in cans.

The acceptability of certain root crops such as potatoes, onions and carrots is unaffected after treatment which will prevent sprouting during storage. Irradiation, however, affects the sugar content of stored potatoes and sweetening determines the storage limit[4,5]—a period of about nine months at 68°F. Irradiation induced metabolic changes in potato tubers have been studied in considerable detail, particularly[6] in the U.S.S.R. Unlike the other applications, which are based on elimination of contaminants, this one stems from a radiation effect on metabolism, resulting in the arrest of germination in tubers.

In the three applications referred to so far, quality changes do not detract from the usefulness of the process so that they may be recommended for consideration of commercial exploitation.

The susceptibility of moulds to radiation treatment brings fruit preservation into the low dose category and there is some promise of an application here. Room temperature storage and refrigeration life of strawberries may be increased with a dose which has no effect on quality[7]. Effective elimination of mould with increasing dose is shown in *Figure 1.*

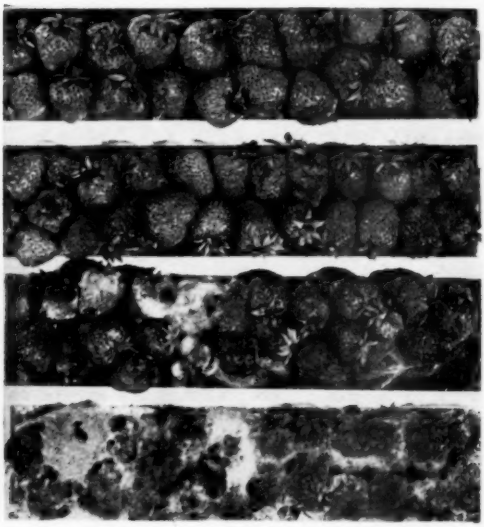

Figure 1. Prevention of mould growth on strawberries during storage of six days at 20°C. The doses, working from top to bottom, were 4 × 10⁵ rad, 3 × 10⁵ rad and 2 × 10⁵ rad respectively, the bottom sample being the control. (Courtesy A.E.R.E. Crown copyright reserved)

Peaches resist radiation damage at a dose high enough to keep them free of rot for useful extended periods[8]. Experiments on oranges and lemons show that a delicate balance exists between the dose required to provide extension of shelf-life, *i.e.*, to inactivate contaminating fungi, and the dose which produces radiation injury[9]. Radiation damage to fruits is mainly associated with softening, and this has been correlated with pectin changes[10,11]. Some loss of flavour is also evident in irradiated fruits, particularly apples and pears.

Quality Loss with High Doses

Unlike fruits, vegetables require high dose treatment to achieve the sterility required for useful increase of shelf-life, and changes induced in colour, flavour and texture render such a process impracticable[1]. Leafy vegetables lose crispness and flavour while peas, beans and carrots become soft and discoloured. The refrigeration life of blanched products might be extended using low doses but otherwise no commercial potential for radiation is apparent.

Disagreeable odours and flavours produced in fish by irradiation detract seriously from its usefulness here. In fatty fish rancidity of the oil is apparent, while in other species like salmon, pigment is bleached and brown discolourations appear in white fleshed species. The storage life of fish has been enhanced by using low dose irradiation combined with antibiotic treatment[12]. Shellfish such as oysters, crabs and shrimps resist radiation damage and might be successfully treated.

Of all the foods milk[13] is the most sensitive to flavour changes which become detectable at 0·02 Mrad, but although no application is foreseen it is receiving considerable study, particularly in our own laboratories, in order to gain information which might be applied to other foods.

The greatest potential of radiation lies perhaps in its application to the preservation of fresh meats and meat products. If storage of fresh or partially cooked meat at room temperature is considered, then an adequate degree of safety must be assured with respect to the food poisoning organism *Clostridium botulinum*. A dose of 5 Mrad is required to achieve the degree of safety ensured by heat processing. At this dose level objectionable changes in colour, odour and flavour are readily detected in all meats, although some suffer less damage than others. The nature of the chemical changes induced in meat by radiation has already been the subject of intense investigation[14]; protein degradation, fat oxidation and change in the nature of the pigments has been observed. Analysis of the volatiles of irradiated ground beef compared with control beef shows that such compounds as acetaldehyde, acetone, methyl mercaptan and dimethyl sulphide are present in increased amount[15]. Degradation of sulphur containing amino acids present in proteins is no doubt indicated. The contribution of volatile bases to odour of irradiated beef has also been studied[16]. Methylamine and ethylamine are the major amines present—several have not yet been identified. It is suspected that irradiated non-protein nitrogen compounds are their principal source. The odour of rancidity has been shown to be a

substantial component of off-odour in irradiated cooked pork so that reactions involving the lipids are also involved[17]. Although rancidity can be successfully eliminated by the addition of certain antioxidants to the meat before treatment, it is extremely unlikely that all the irradiation odour and flavour changes can be successfully eliminated by addition of suitable inhibitors; the chemical changes are obviously too complex.

Residual enzyme activity in fresh meat is affected only to a limited extent by sterilization doses of radiation[18]. Even if it were possible to sterilize fresh meat without quality change, the problem of autolytic degradation during room temperature storage still remains. For this reason attention has now turned to the treatment of cooked meats, although chemical changes influencing quality are induced here also and the presence of certain chemical components can be related to taste panel scores[19]. Heat conditions for proteolytic enzyme inactivation have been investigated[20]. Long term room temperature storage of canned cooked meats is possible, of course, without the use of radiation, but these meats tend to be overcooked to ensure bacteriological safety so that the quality is generally poor. It is hoped that by using radiation to eliminate micro-organisms, the heat treatment that will be required for enzyme inactivation will be mild enough to ensure a high quality product, particularly with reference to texture.

Low dose treatment designed to effect pasteurization of meat has been applied to whole chickens[21]. Chicken carcasses irradiated with doses up to 0·8 Mrad show no detectable flavour change if roasted soon after treatment. Storage life at 1°C may be extended although there is some loss of quality before the onset of microbial spoilage. Bacon irradiated at 0·2 Mrad can be differentiated from control samples in flavour tests, and as with chicken, although bacterial spoilage is retarded during storage, the flavour is unacceptable due to non-bacterial changes which occur[22]. A low dose process which, on quality considerations, might be successfully applied to meats is that designed to destroy parasites. A dose as low as 0·01 Mrad renders the immature stages of the parasite worms *Trichinella spiralis* and *Cysticercus bovis* incapable of development when transferred to suitable hosts[23].

Nutritive Value and Possible Toxicity

Attention has recently been focused on the possible toxicity of irradiated food in connection with the suspension of plans to build a large food irradiation plant in the U.S. This plant was to be part of the U.S. Army Ionizing Radiation Centre and the project was estimated[24] to cost 7½ million dollars. Press reports of the announcement stressed references made to harmful effects observed in experimental animals fed on irradiated food[25,26]. Observations made were loss of fertility in dogs, internal bleeding and blindness in rats, and heart damage in mice. However, a detailed account of the reasons for making the decision to suspend the building of the plant was given at a U.S. Congressional hearing early this year[27]; it was emphasized that the findings regarding toxicity were premature and inconclusive and it was rather considerations of the quality of treated food and the value of radiation processed food to the U.S. Army which led to the decision being made.

KRAYBILL, who was for many years intimately connected with the U.S. Army's feeding tests on irradiated food, has given an adequate explanation of the observations previously referred to on experimental animals[28]. The chemical changes induced in the food do cause some nutritional damage but this should not be confused with the production of toxic compounds; there is, as yet, no evidence of toxicity. The vitamins particularly, and proteins and fats have already received considerable attention with regard to nutritional changes.

Vitamins

A somewhat confusing picture has arisen regarding the effect of irradiation on vitamin K. Rats receiving diets containing high proportions of irradiated beef developed vitamin K deficiency[29,30], but similar symptoms were produced with non-irradiated as well as irradiated cooked pork[31]. This vitamin occurs in foods and is also synthesized to some extent by intestinal bacteria and excreted in the faeces; the rat obtains much of its normal requirement by coprophagy, *i.e.* consumption of faeces. Certain carbonyls present in the irradiated meat appear in the faeces and prevent this practice. The vitamin K content of the faeces of rats fed irradiated and non-irradiated meat diets are similar. It has been suggested that vitamin K in meats is destroyed by substances produced by irradiation or cooking. The addition of small amounts of the vitamin to treated diets failed to reverse the deficiencies, but supplementation separate to the diet corrected the effect. Vitamin K in green vegetables or in pure form is stable to irradiation[32]. Deficiencies of this vitamin in rats might be due to its faulty absorption from the digestive tract[31].

Other fat soluble vitamins are sensitive to radiation. Large losses in carotenes and preformed vitamin A have been reported in foods[33–36]. Poor reproductive performances in rats fed on irradiated

semi-synthetic diets may be attributed to vitamin E destruction[37] and this has been confirmed feeding 45 per cent irradiated beef[38].

The water soluble vitamins show varying degrees of sensitivity. Thiamine is perhaps the most sensitive, its destruction in beef being related to both dose and temperature[39]. Its losses vary greatly in different foods. A 40 per cent loss occurs in bacon at 0·46 Mrad and a 60 per cent loss in trout at the same dose[40]. In scallops the reported loss is only 10 per cent at sterilization doses[41] and no loss of thiamine was observed in dried milk[42].

Nicotinamide in food is relatively stable except in the presence of high levels of ascorbic acid, hence the large loss reported in peaches[42]. Forty per cent destruction of riboflavin occurs in pork sausage[41] and turkey[42] at sterilization levels, but only 10 per cent in beef[43] and scallops[41]. Pyridoxine is reported as 25 per cent destroyed in beef[43] at high doses with less destruction in other foods[35,41]. Choline, folic acid and inositol are stable in beef[43] but destroyed in aqueous solution[44]. Ascorbic acid is particularly sensitive to radiation, but here again the amount destroyed depends upon the presence of other compounds—for example, this vitamin is protected in milk[45].

Certainly vitamin losses do occur in irradiated foods, and the magnitude of these losses varies from one type of food to another, and also with the level and conditions of irradiation. It is important to stress, however, that foods treated by conventional accepted heat processing methods suffer vitamin losses also, and this fact does not prevent their use. Losses after heating and after irradiation have been compared, and it appears that the latter causes less damage than cooking[31]. Destruction of B vitamins is comparable on irradiation and on canning, although the carotenes are more susceptible to radiation[35,41,46].

Proteins and Fats

Proteins suffer little change in their nutritive value after irradiation. Some biological values before and after treatment are compared in *Table 2*; for each of these proteins no change in digestibility was noted. The lowered biological value for milk has been shown to be due to binding or destruction of cystine[47]; there is as yet no explanation for the loss with pea protein. Losses are, in some cases, no greater than are observed with certain heat processing. A study of the effect of irradiation on the amino acid composition of milk and beef has shown that glutamic acid, aspartic acid, serine and glycine are most seriously reduced[48]. Fortunately these acids are non-essential for animals and man.

The peroxide number of fats increases on irradiation, but the peroxide number in irradiated foods rarely exceeds 100 and at this level fat is not toxic[49].

Table 2. The biological value of selected proteins

Food	*Dose (Mrad)*	*Biological value*		*Ref.*
		Raw	*Irradiated*	
Evaporated milk	2·79	89·5	81·8	58
Beef	2·79	78·0	78·6	58
Lima bean	2·79	48·2	47·2	59
Lima bean	9·30	48·2	48·3	59
Peas	2·79	58·3	50·5	59
Maize	2·79	47·0	47·1	60
Wheat gluten	2·79	41·6	41·7	60

Toxicity

In the U.S. a large research programme has been initiated by the Army authorities to examine the possible toxicity of irradiated food. A wide variety of foods have already been tested, using rats, dogs and monkeys as test subjects. Animals are fed diets containing a high proportion of the irradiated food over two-year periods. Short term human feeding tests have also been conducted[49]. Little of the animal work has yet been published in detail although many of these trials are now well advanced.

Irradiated pork[50], organ meats[51], and beef[38] have been examined; no effects were noted to suggest that they are unwholesome. Irradiated semi-synthetic diets[37] have produced no effects either, apart from that due to vitamin destruction. Such a diet sterilized by irradiation supported growth in mice equally as well as that sterilized by steam[52]. Satisfactory progress in feeding trials involving other foods has been reported[49,53,54], although in short term studies there was some evidence of low level toxicity in peaches irradiated at 5·57 Mrad, but not at 2·79 Mrad.

Long term tests in our own laboratories are not yet complete. In support of our programme on grain disinfestation, irradiated wheat has been fed to rats over four generations and no ill effects have been noted to date; the test will be completed within a year. Observations being made include those on growth, lactation, reproduction, disease resistance and tumour incidence; haematological examination is carried out, biochemical tests applied to urine and organs examined histologically at post mortem. A short term trial in which irradiated grain was fed to poultry has been completed; no effects were observed in body weight or egg production[55]. A study of irradiated whole egg is being undertaken at

present with reference to the *Salmonella* application, and some work on the feeding of irradiated potatoes to pigs has already been reported[58].

Conclusions

It seems probable that irradiated food will eventually be accepted for human consumption and that certain low dose processes will find application. This new method of food preservation is being studied in the light of existing methods with which it will have to compete. The pilot plant, referred to in *Part I*, will make possible more accurate assessment of the costs of irradiation. A U.S. plant of even greater capacity is to be built for food studies according to a very recent announcement, and no doubt valuable information will become available regarding economic feasibility[57].

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POLYTECHNICAL EDUCATION IN THE U.S.S.R.

T. NOLAN

An outline is given of the educational structure in the U.S.S.R. showing how the emphasis is laid on technical training. Miss Nolan spent three months in Russia in Moscow, Kiev and Odessa, visiting schools and Pioneer Houses and attending lectures at Pedagogical Institutes for the training of teachers

THE general principles of education in the Soviet Union are laid down in the official programme of the Communist Party, while laws and decrees on education are made by the Supreme Soviet of the U.S.S.R. and its Council of Ministers. Each republic has its own Ministry of Education which is, however responsible to the Central Ministry in Moscow. The organization of schools and higher education institutes has a uniform pattern, slightly modified in the different republics to cater for special local needs in the matter of language.

Soviet theorists believe that education must be geared to the needs of the state, the greatest of these being more rapid progress in science and technology. Study must be linked with socially useful work, not only in specialist courses, but throughout the ordinary school years. The type of education given in Soviet schools then, is described as ' general and polytechnical '. It aims at all-round development of the pupils, giving them a basis for a choice of profession and a definite training for practical work. All pupils, on leaving school, should have a general conception of up-to-date production and its basic elements (energetics, machine technology) and of the main laws of science in use both in industry and agriculture, as well as certain skills which are essential for practical work.

Educational Structure

The standard type for children between seven and seventeen years throughout the Soviet Union is the ' Ten Year School ' which comprises three units, Primary, Middle School, and Senior School. Usually all three departments are housed in the same building but in some rural areas they are separate, owing to lack of accommodation. In many towns schools work on a ' two-shift ' basis for the same reason. The following observations are made on the basis of a visit to the U.S.S.R. at the end of 1958 when the schools were in a state of transition from the ' Seven Year ' to the ' Ten Year ' school. In 1952 it was intended to make seventeen years the compulsory leaving age for all, as it is in a hundred and twenty two towns in the U.S.S.R. This has not yet been achieved and for some pupils, especially in rural areas, fifteen is the school-leaving age. Thus in 1958 there were some 31½ million pupils receiving a general education in the 215,000 schools, of whom about 2 million were youths and adults who were already working. Of the ten million or so in the 5th–7th year school class during 1955/6 about 4½ million went on to the 8th–10th year in 1958/9. In addition there are between 1¾ and 2 million attending secondary specialized schools (8th–10th year) (see *Table 1*) and receiving some form of technical training; many of these go on to centres of higher education[1].

Table 1. Enrolment at secondary specialized schools[1]

	1956	1957	1958
Total	594,600	557,200	584,100
Day	386,300	358,400	363,700
Evening	78,000	71,700	75,200
Other	130,300	127,100	145,200

Also certain special schools exist for children who are mentally retarded or physically handicapped, but such pupils are only assigned to a special school on the recommendation of a doctor after they have attended the Ten Year School for at least twelve months. Children who show exceptional talent in music, art, ballet, or who wish to take up a military career, are accepted by special schools for these courses on passing a highly competitive examination. Other schools which do not conform to the general pattern are the ' Experimental Schools '. These are certain Ten Year Schools in various cities, chosen by the Ministry for the purpose of trying out changes in the standard curriculum for schools. These number about one hundred and fifty. However, the great majority of Soviet children attend the Ten Year School, following a uniform syllabus, using the standard textbooks and taking the examinations directed by the Central Ministry. Outside the Russian Federal Republic, lessons are conducted in the native language, but Russian language and literature are compulsory subjects.

School buildings vary little from region to region. They contain a library with a full-time librarian, a medical room for the school doctor, workshops and equipment for practical work with a full-time instructor, a Pioneer room for the use of the youth organization and also a methods room, which contains both visual aids supplied by factories controlled by the Ministry of Education, and those made by the pupils themselves. Each school has three laboratories for biology, chemistry and physics.

New pupils are put into classes in order of registration; there is no system of 'streaming' and it is rare for a pupil to repeat a year's work. Backward pupils are given extra coaching after school hours by the teacher, an older pupil or by the class tutor, a paid assistant who supplements the work of the teacher.

Higher Education

At the end of the tenth year pupils take a leaving examination conducted by a special committee of teachers and examiners. In addition to a written essay on Russian language and literature, it includes oral tests on algebra, geometry, physics, chemistry, one foreign language and the history of the U.S.S.R. Successful candidates who obtain a very high mark are awarded a gold medal which automatically admits them to an institute of higher education. Those who do not achieve this must attempt the highly competititive examinations set by the higher education institutes. Such institutes include the universities and also a wide range of colleges which offer a five-year course in special subjects,

Table 2. Enrolment of students at centres of higher education[1]

	1956	1957	1958
Total	458,700	438,300	453,300
Day	231,200	219,700	213,900
Evening	32,600	34,700	42,200
Other (corresp.)	194,900	183,900	197,200
Break-down into subjects			
Industry and Construction	151,100	147,700	152,500
Transport and Communications	31,100	30,300	29,000
Agriculture	48,700	51,800	56,600
Economics and Law	35,200	34,000	38,100
Health, Physical Culture and Sport	31,000	30,800	31,900
Education	158,600	140,300	141,300
Arts and Cinematography	3,000	3,400	3,900

N.B. The pure sciences and arts are included in such sections as 'Industry and Construction', 'Education', *etc.*

Teachers' Training Colleges, Institutes of Engineering, Machine-Building, Medicine, Law, Transport and Agriculture. All are described as having 'University Status', (*see Table 2*). In 1958/9 there were 2,179,000 students at these institutes of higher education of whom 1,180,000 were day students[1].

Special preference in the entrance examinations to the centres of higher education is given to candidates who left school at fifteen and continued their studies at evening classes. Although the content of these 'higher' courses varies certain subjects are compulsory: Marx-Leninism, political economy and dialectical materialism. Special emphasis is placed on practical work and students at Technical Institutes are required to spend up to thirty eight weeks in factories. On completion of these courses those students who do not go on to the higher degrees apply for posts which are advertised in the institutes. Successful candidates may be asked to work on new construction sites away from the towns and are obliged to stay in such posts for at least two years after graduation.

School Subjects

The whole school syllabus is compulsory. The programme for the first to the seventh forms includes one foreign language, mathematics, physics, chemistry, biology and also one period per week of technical drawing and two periods of practical work in the school workshop. As the seventh year marks the end of school for some children, there is a leaving examination, both written and oral, on the Russian or native language, arithmetic and algebra. School-leavers have a limited choice of jobs. Factories or commercial enterprises notify the headmaster of vacancies and he arranges interviews for suitable candidates.

In addition to general subjects which include mathematics, chemistry and physics and one foreign language, pupils in the eighth to the tenth years must study astronomy and psychology. Two periods per week are spent in the study of agriculture and the electrotechnics. For these senior forms, a set amount of time must be left free each term for excursions and visits to factories and farms.

The actual content of lessons in the school is not very different from that in England, except that of the history lesson. Chemistry lessons deal with chemical processes used in industry and the biology teacher tries to relate his subject matter to agriculture in the Soviet Union. English is given preference as a foreign language, followed by French and German. The text books combine

efficient language teaching with subject matter designed to inculcate socialist principles. The science laboratories are surprisingly unimpressive, with inadequate equipment for individual practical work and although visual aids abound in all departments, they do not seem to be used often during the lessons.

It is, however, quite misleading to assess Soviet education solely on the basis of observation in the classroom. Every school has one or more 'patrons'. In the towns the patron is a factory or commercial enterprise; in rural areas, a collective or state farm. A close connection is maintained between the school and its patron, which supplies equipment for technical lessons, machines and tools for practical work and also special facilities on its premises for groups of school children to study industrial or agricultural processes. In Odessa, teachers supervise classes as they assist at certain processes in champagne making at a local factory. In Kiev, groups of children make simple machine tools in the school workshops and sell them to their patron factory. Rural schools are allotted a plot of land for class projects. Usually they concentrate on producing one crop with the aim of increasing the yield or improving the type of crop.

Youth Organizations

The role of the school and of the teacher extends beyond the provision of formal classes. The two youth organizations, the Pioneers and the Komsomols are closely associated with the schools. The great majority of children between nine and fourteen years of age belong to the Young Pioneers, an organization which aims to increase social consciousness and to supplement the practical work done in school. Each school has a paid full-time Pioneer organizer and several part-time assistants who may be students or factory workers who belong to the Komsomol movement designed for Soviet youth over fourteen years of age. Pioneer groups inside the school help to maintain discipline and to organize voluntary after-school activities. Groups outside the school organize community work, often helping to build on factory sites or blocks of flats. Most towns have a Pioneer House under the supervision of a full-time organizer and a staff of specialists in technology, music and art, who are paid by the Ministry of Education. Large cities like Moscow and Kiev have a Pioneer Palace with three well-equipped departments for technical circles, music and art circles, and general recreation. The children who use these may be regular members of a Pioneer group or casual attenders.

In addition to the activities organized by the youth groups, teachers and factory workers use the school building for meetings of various out-of-school circles for children over eleven years of age. The Vladimir Ilych School in the Moscow region provides its technical circle with a tractor which is taken to pieces by the children during the winter and set up again for use on the patron farm in spring. Schools near Kiev have access to a biological station staffed by professional biologists and gardeners, which provides accommodation for school children and teachers engaged in projects connected with their biology lessons.

Future Plans

It is not easy to keep up-to-date with trends in Soviet education. The system is constantly adapted to new social needs. Last year Mr Kruschev commented on the problems raised by the increasing number of school children who are staying at school up to the tenth year. Higher institutes of education cannot accommodate all those who apply for the courses, yet there is a constant need for trained specialists in every field and skilled workers in industry and agriculture. In his address to the Presidium, Kruschev suggested further improvements in higher education with even greater emphasis on practical work and he proposed that the Institutes should take in a greater number of students who have already spent a period of time at work. He implied that the existing school system might produce too many 'academic' students and suggested that all pupils, except those who were specially talented, should spend their final school years in factories or farms specially equipped to train young people and at the same time to allow them to finish their general education. It appears that these changes are to take place during the next two or three years. Meanwhile, during the transition period 'Ten Year Schools' and specialized secondary schools will supply the Higher Education institutes with candidates specially selected for their academic ability. The rest will be diverted into industry or agriculture after their seventh year, with the opportunity of continuing their studies at part-time or evening classes.

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SURVEY

New Research Laboratories

It is exciting to see research associations mature, and recently two new D.S.I.R. research organizations have come of age and moved into their own buildings.

C.S.F.R.O.

The first was the Coil Spring Federation Research Organization, whose new laboratories at Sheffield were opened by Sir Harry Melville, Secretary of D.S.I.R. on March 24th. This organization has been in existence since 1945, and its services include pure and applied research to enable the whole coil spring industry to advance its technical processes, and research into members' individual technical problems. The full members must be manufacturers of springs, but firms using springs or supplying materials or equipment to spring manufacturers may be associate members.

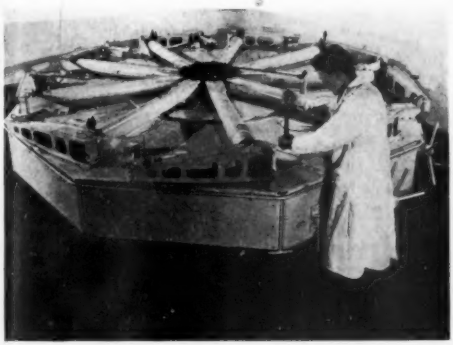


Figure 1. Multiple fatigue testing of heavy hot-formed springs with a maximum load of 8½ tons on a 12½ h.p. radial machine

The equipment in the new laboratories is extensive including machines for heavy fatigue testing, general mechanical testing, experimental heat treatment and electroplating. In the fatigue testing laboratory, for example, there are two 12½ h.p. machines capable of applying a dynamic load of 9 tons, used for fatigue testing of up to 18 heavy coiled springs (*Figure 1*). The laboratories contain a number of machine tools and a shot-peening unit which automatically rotates the object under treatment whilst traversing it with the shot stream. In a materials testing laboratory there are machines for determining macro hardness, tensile and torsional properties of wires and load-deflection characteristics of small springs. Interesting work is being carried out, for example, on the torsional fatigue properties of titanium wire, the improving of shot-peening conditions and, in cooperation with Sheffield University, the improving of the heat treatment of copper–beryllium springs.

The Heating and Ventilating Research Organization

The second new research laboratory is a younger offshoot of an even older form of engineering; the Heating and Ventilating Research Organization, which started life in 1955 as the Heating and Ventilating Research Council and achieved research association status in 1959, is now attractively housed at Bracknell. In addition to studying existing techniques of heating and heat transfer, ventilation, air movement and air conditioning, they are also developing new processes, notably an intermittent heating system which varies the time of ignition of an automatically fired boiler in accordance with the temperature of the building. The control, however, is from the temperature of the water in the heating system, and not directly from the temperature of the rooms in the building. Investigations are also being made on chimney design, reduction of noise in heating and ventilating systems, and measurement of ventilation rate.

British Railways Research Laboratory

British Railways are re-organizing, co-ordinating and expanding their Research Department, and their new building at Muswell Hill, in the precincts of Alexandra Palace, which was opened on March 11 by Sir Brian Robertson, is the first of several centres which are designed to serve wide areas. This building, for example, houses the headquarters staff of the Chemical Services, the London Area Chemical Laboratory which serves territories extending to Sheerness, Aldershot, Reading, Oxford, Leamington, Rugby, Peterborough and the Wash, and the Building Materials Laboratory and Corrosion Laboratory, both of which serve the whole country.

Solar Rays used in Production of Chemicals

The chemical action of ultraviolet radiation from the sun is being used in experiments being carried out at a solar energy laboratory operated by the University of Algiers. A steerable paraboloid aluminium mirror, twenty-seven feet in diameter, which can be made to follow the sun is being used, and the raw materials are nitrogen and oxygen from air and water; the products are nitrogen fertilizers, but the manufacture of other chemicals is also being studied. French scientists hope that it may be possible to establish solar factories in the Atlas Mountains or on the northern fringe of the Sahara desert to produce fertilizers for use in arid regions. (UNESCO).

BOOK REVIEWS

Progress in Inorganic Chemistry: Volume I

F. A. COTTON (*Ed.*)

(*ix+566 pp; 9¼ in. by 6 in.*)

New York and London: Interscience Publishers, 1959. £5 9*s*

HERE is the first of a projected annual series of volumes offering a new forum for the exchange of views and for the critical review and evaluation of advances in the many aspects of inorganic chemistry. The series aims to contribute to filling the need for fruitful communication at Ph.D. level among the very diverse branches of this discipline. The present vast expansion of inorganic chemistry has been accompanied by a change of complexion; the classical inorganic chemist indeed would find no point of contact in this volume, perhaps due to the deposition into the subject of many peripheral aspects of physical, physical-organic, structural, and theoretical chemistry and even of physics which are inconvenient of precise classification.

Whether this venture is but another new journal in disguise to increase the burden on the pocket and time of the already over-bedevilled chemist or whether it fulfils a need not already met by the review journals must be decided on its merit. For instance, the topic of metal–ammonia solutions is more succinctly covered in the recent review by SYMONS (*Quarterly Reviews* (1959) **13,** 99), and may be preferred by the non-specialist, while JOLLY's exposition may appeal to one intending to specialize in the field. The first volume makes a good start with seven monographs by contributors eminent in their chosen subjects. There are chapters by WILKINSON of Imperial College and COTTON of M.I.T. on *cyclo*pentadienyl and arene metal compounds (125 pages), HENNIG of Argonne National Laboratory on interstitial compounds of graphite (102 pages), BECKE-GOEHRING of Heidelberg über Schwefel-Stickstoff-Verbindungen (128 pages), JOLLY of California on metal–ammonia solutions (48 pages), MALATESTA of Milan on the effect of inner orbital splitting on the thermodynamic properties of transition metal compounds and coordination complexes (98 pages) and by WARD of Connecticut on the structure and properties of mixed metal oxides (84 pages). The author index is excellent, the subject index less so.

Some of these reviews are timely in that no very recent comparable survey is available. The treatment in each case avoids both the terseness of a highly compressed literature survey and the superficiality of a general review, and is scholarly and readable. Those seeking an informed and comprehensive, but not tediously exhaustive, account of the topics offered, spiced with authoritative opinion, may well find satisfaction here. Yet any addition to the proliferation of literature which few have time to read must show rather special justification for its appearance and continued existence, and, considerable though the merits of this volume may be, judgment must presently be suspended on the desirability of the proposed series.

Production is first rate, and the literature coverage extends to early 1959 in certain cases. The price sets this volume in the higher journal bracket which rather tends to defeat the object of the series and places the onus of expenditure on libraries. E. B.

Principles of Modern Building. Volume I

BUILDING RESEARCH STATION

(*x+302 pp; 9¾ in. by 6 in.*)

London: H.M.S.O. 20*s*

THIS book follows the pattern of its well-known forerunner but the years of waiting for this new edition have produced important changes of principle. Whereas the original book was Vol. I of a projected four volume edition, dealing with the major elements of building, and representing the work of a single author, Mr R. FITZMAURICE, the new edition of the work is to comprise two volumes only. Furthermore, a somewhat different treatment has been adopted, the reasons for which are stated in the preface. The book consists of two parts, Part I dealing with ' the functional performance of the building as a whole ' and Part II dealing with ' specific applications to walls and other vertical elements '.

The subject matter of the original book has been drawn upon in both parts of the new volume with certain revision and new material added. The book too, is now the collective work of the staff of the B.R.S. as a whole and no longer the work of one man. This concentrated effort backed by the accumulated results of research and experience over the years results in a work of outstanding importance.

Naturally in the above circumstances comparisons are bound to be made, with the dice loaded heavily in favour of the original book which was held in such esteem for so long. It is as well to deal with some of these first. The earlier work gave practical notes and suggested treatments, printed in bolder type, at the end of each section. Again the sub-headings were inset in the text and were also in bolder type. These bold-type sub-headings facilitated reference whilst the practical treatment notes served both to summarize and assess the points dealt with in the text. By comparison, the sub-headings in the new book have gone into semi-retirement. It is not very clear why this should be so, though perhaps practical treatment notes are not very possible for attachment to the new chapters on daylighting and building economics and perhaps others. Two of the great problems which emerge in the first part of the book on ' whole buildings ' are those of comparative emphasis which might suggest priorities of importance where imponderable factors clearly exist between functions, and the weight of evidence which results from individual treatment in chapters. In a curious way, for example, the chapter on daylighting, by virtue of its excellent diagrams, text and illustrations overshadows most of the work in Part I which is perhaps more than its due, though its importance deserves emphasis because it is so much neglected in practice. Some inclusion of photographs of whole buildings, particularly some of our new high ones, would have enlivened the first part of the book and might have helped with this matter of emphasis, though the dangers and problems of selection were perhaps too much for the legal department

of the B.R.S. It is surprising nevertheless to see so little reference to the new problems which arise in the new 18–30 storey buildings now becoming general in the big cities—some particular mention might have been expected under the headings of Heat Insulation and Fire Protection, as examples.

It is fairly easy to find fault with some aspect or omission in a book of this magnitude, and it is more just to leave this review with a real appreciation of its publication and the filling of the void left when the first volume was out of print. Here is in fact a summary of the up-to-date work and coverage of the research station—an invaluable book to the whole building industry—carefully edited with appendices in the form of a glossary, lists of British Standards and Codes of Practice. It will certainly be found in the libraries of all who make a contribution to building. J.R.A.M. and D.R.H.

Crystal Chemistry of Simple Compounds of Uranium, Thorium, Plutonium and Neptunium

E. S. MAKAROV

(*Translated from the Russion by* E. B. UVAROV)

(*iii+145 pp; 9¼ in. by 6 in.*)

New York: Consultants Bureau; London: Chapman and Hall. 42*s*

THIS book is a translation of a Russian work (published in 1958) which reviews studies on the crystal structures of compounds of the actinide elements thorium, uranium, neptunium and plutonium. Earlier reviews by ZACHARIASEN and others have surveyed the compounds of these elements with the non-metals, but the present work includes also information on a large number of intermetallic systems never before collated in a single volume. For this reason its appearance is to be warmly welcomed.

After preliminary chapters on the general principles of crystal chemistry, the greater part of the book is devoted to a systematic descriptive account of the known structures of compounds of the four elements in question with all the remaining elements of the periodic table. Some of these compounds have, of course, already been recorded in *Structure Reports*, and in these cases comparison of the two works shows that the treatments are closely comparable in scope and style. The merit of the volume under review, however, is that it records all structures published up to June 1957, whereas *Structure Reports* at present cover only the years prior to 1952.

A final chapter of the book is devoted to a scholarly discussion of the difficult problem of the electronic configuration of the actinide elements, which the author, following SEABORG, prefers to describe not as '*5f* elements' but as 'elements of the *5f–6d* region'. He also emphasizes by numerous examples the close chemical relationship of these elements not only with the lanthanides on the one hand but also with the elements of the IV*a*, V*a* and VI*a* sub-groups on the other, concluding from his discussion that the term 'actinide' is not wholly unexceptionable.

The volume is strongly bound, but in other respects is a poor example of book production. Printing appears to have been entrusted to a printer inexperienced in the setting of technical matter and quite inadequately equipped with the wide range of sorts required for such work. As a result, there are a number of printer's errors and a much larger number of typographical solecisms which will irritate, and even confuse, the sensitive reader. There is no index, but every compound can be readily traced from the numerous and systematically arranged tables. The translation is excellent. R.C.E.

Tools of Biological Research

HEDLEY J. B. ATKINS (*Ed.*)

(*xvi+183 pp; 9 in. by 5¾ in.*)

London: Blackwell Scientific Publications Ltd. 37*s* 6*d*

PROCEEDED by an introduction by Sir Cyril HINSHELWOOD, P.R.S., this is a collection of ten papers, each on a different topic, delivered at a Symposium held by the Surgical Research Society in October 1958. The Society voted on an original list of about twenty subjects, and the ten chosen are those which were generally felt to be of the greatest interest. As the papers were restricted to forty five minutes duration, the treatment of each tool is necessarily brief; little more is attempted than a qualitative description of the principles involved, and some examples of the field of application thereof. The work is therefore useful light reading for a specialist wishing to keep himself aware of advances in the techniques of other fields; but, one paper excepted, it seems unlikely that it will be of great value to a worker himself proposing to enter one of these fields.

The book is well produced and singularly free from misprints. Both plates and diagrams are referred to as 'figures', and as the plates do not always face the relevant text, one's first impression is that some of the figures have been accidentally missed out. There is a departure from normal practice in using italic capitals for chemical symbols.

The work contains an excellent paper by Dr HONOR B. FELL, F.R.S., on *Tissue Culture* (14 pp.) and another by Dr L. BRENT on *Tissue Transplantation* (14 pp.). It is Dr BRENT'S contribution which is sufficiently detailed to allow the reader to begin such work himself. The longest paper, by Dr David ROBERTSON, is about *Electron Microscopy*; there are 48 pages on this topic, three quarters of them devoted to techniques, and the remainder to some recent findings with the electron microscope. There are one or two obscurities in this contribution, for example the apparent suggestion that an electron beam can be focused because, in some respects, it exhibits wavelike properties.

Other techniques clearly described are cell-weighing with the microscope (Dr R. BARER, 21 pp.), *Mass Spectrometry* (Dr P. HUGH-JONES, 13 pp.) and, very briefly, *Image Intensification* (Drs B. COMBEE and P. J. M. BOTDEN). A paper on *Electrophoresis* (Professor N. H. MARTIN, 9 pp.) explains the principle with the sentence 'if a current is passed through a solution of a mixture of proteins, the components of that mixture will migrate with varying velocities which will depend largely on the differences in the character and magnitude of their free

surface charge, although size and shape may play a part'. Although this is not untrue, it is misleading in that the migration velocities are determined by the electric field strength applied, not by the current. The same kind of confusion between a constant-voltage and a constant-current type of electric generator is evident also in an otherwise clear chapter on *Flame Photometry* (Professor R. H. S. THOMSON and Dr R. W. BAKER, 15 pp.) which, discussing photo-conductive cells, says 'if a current therefore is allowed to flow through the cell, the decrease of resistance on illumination will cause an increased current to flow'.

Interestingly, the book begins with a discussion of a tool which is not made of hardware (*The Design of Experiments*, by Dr P. ARMITAGE, 9 pp.). The emphasis here is on the statistical treatment of data.

The remaining chapter (*Electromanometry*, by Dr J. P. SHILLINGFORD, 15 pp.) is not, in this reviewer's opinion, very satisfactory. The writer describes five kinds of bridge circuit in which a suitable pressure transducer may be included. Of these, two must be used with a.v. excitation, two can be so used, and 1 (optical) can employ a switched light beam. Despite this, Dr SHILLINGFORD says next that the amplifiers used in electromanometry must be of the direct-coupled variety. A discussion of the difference between a capacitor-coupled and a direct-coupled amplifier follows, illustrated by a diagram in which signals do not undergo phase-inversion in passing through a valve. The possibility of carrier methods is then briefly mentioned. Later on, the writer seems to suggest that the effect of damping a low-pass resonant system is to *increase* the rate of fall-off of response above the resonant frequency. Later on again, he uses the word 'true' to describe the response of a critically damped recording system.

My thanks are due to Mr A. F. HUXLEY, F.R.S., Dr E. N. WILLMER and Mr H. E. TUNNICLIFFE for advice in the preparation of this review. Responsibility for the views expressed is, however, my own. P.E.K.D.

Non-Homogeneity in Elasticity and Plasticity

Proceedings of the I.U.T.A.M. Symposium
W. OLSZAK (*Ed.*)

(*xxiv+528 pp; 10 in. by 6½ in.*)

London: Pergamon Press Ltd £5

IN SEPTEMBER, 1958, the International Union of Theoretical and Applied Mechanics held a symposium on Non-Homogeneity in Elasticity and Plasticity. This volume contains fifty-two theoretical and experimental papers including two surveys, one on Stability Problems of Non-Homogeneous Viscoelastic Media and the other on Plastic Non-Homogeneity: a survey of theoretical and experimental research. It is edited by Professor W. OLSZAK of Warsaw; with the exception of eight papers in French and two in German, all are in English. The range is indicated by the divisions: I, Elasticity; II, Plasticity; III, Rheology; IV, Dynamics and Wave Propagation; V, Statistical and Micro-Non-Homogeneity; VI, Varia.

The quality of contributions to symposia is notoriously variable. Some of these papers are devoted to a particular point in a particular problem but most are of wider interest and the whole does give a broad picture of the 'state of the art'. The publication of discussions is always the greatest problem in symposia. For the participants this is the most important feature but rarely can the published version do justice to the meeting; the present case is no exception. G.K.T.C.

Symposium on Basic Research

D. WOLFLE (*Ed.*)

(*xx+308 pp; 9¼ in. by 6 in.*)

Washington, D.C.: American Association for the Advancement of Science; London: Bailey Bros and Swinfen. 27*s*

THIS Symposium was sponsored by the National Academy of Science, The American Association for the Advancement of Science and the Alfred P. Sloan Foundation and was presented in New York in May 1959. The level of the papers was high and certainly the book is stimulating. The subject in itself is, of course, so wide that the easiest thing is to disagree and criticize omissions but surely the importance of such symposia is to stimulate. It certainly does that. G.K.T.C.

Maritime Organic Moderated and Cooled Reactor

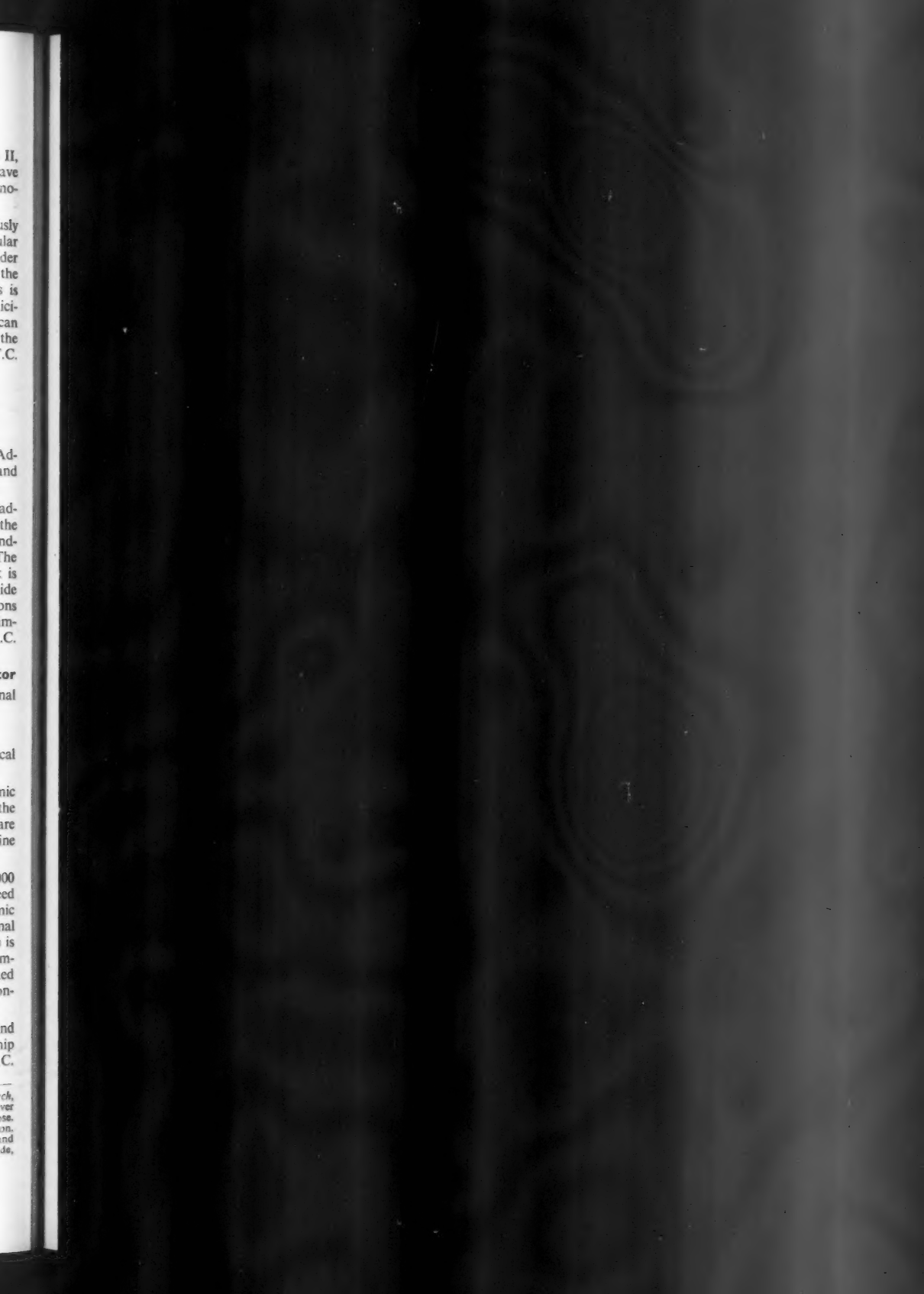
North American Aviation Inc., Atomics International Division, Canoga Park, California

(*xi + 197 pp; 10¾ in. by 8 in.*)

United States Atomic Energy Commission, Technical Information Service. May 27, 1959

SHIPBUILDERS appreciate that the adoption of atomic power in certain types of merchant ships may lie in the near future. Detailed design studies of such vessels are therefore of intense interest to them and to marine engineers.

This report is a study of a tanker to carry about 60,000 tons of oil from Kuwait to the U.S.A. at a service speed of 17·5 knots. The power installation, *i.e.* the atomic power unit (used for steam generation) and conventional turbine machinery (30,000 S.H.P., 425 lb/in.², 650°F) is located aft, as in normal practice. The crew are accommodated in a bridge structure amidships. It is estimated that the operating costs would exceed those of a conventional tanker by 18 per cent.

The report contains much useful information and merits close study by all who are interested in ship design, construction and operation. J.F.C.C.

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